SD11
.A574
#216

USDA United States Department of Agriculture

Forest Service

North Central Research Station

General Technical Report NC - 216

Northern Minnesota Independence Day Storm: A Research Needs Assessment

The U.S. Department of Agriculture (USDA) prohibits discrimination in all its programs and activities on the basis of race, color, national origin, gender, religion, age, disability, political beliefs, sexual orientation, and marital or family status. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (braille, large print, audiotape, etc.) should contact the USDA's TARGET Center at (202) 720-2600 (voice and TDD).

To file a complaint of dicscrimination, write USDA, Director, Office of Civil Rights, Room 326-W, Whitten Building, 14th and Independence Avenue, SW, Washington, DC 20250-9410, or call 202-720-5964 (voice or TDD). USDA is an equal opportunity provider and employer.

Photos throughout the publication courtesy of the Superior National Forest and photos on page 48 courtesy of Mike Ostry and William Mattson of the North Central Research Station.

North Central Research Station
Forest Service—U.S. Department of Agriculture Forest Service
1992 Folwell Avenue
St. Paul, Minnesota 55108
Manuscript approved for publication February 8, 2001
2001

Northern Minnesota Independence Day Storm: A Research Needs Assessment

William J. Mattson and David S. Shriner, eds.

Cooperators:

USDA Forest Service, North Central Research Station

USDA Forest Service, Superior and Chippewa National Forests

University of Minnesota, College of Forestry

Minnesota Department of Natural Resources, Forestry Division

USDA Forest Service, State and Private Forestry Division, St. Paul, MN

ROCKY MOUNTAIN RESEARCH STATION LIBRARY
FORT COLLINS CENTER
240 W PROSPECT RD
FORT COLLINS, CO 80526-2098

THE TRIGGERING EVENT, THE 1999 INDEPENDENCE DAY WINDSTORM

A massive wind and rain storm, a few minutes past noon on July 4, 1999, in northern Minnesota, created an extensive and largely unprecedented blowdown across north-central to northeastern Minnesota, Wisconsin, and southern Ontario. Over 477 thousand acres were impacted in northern Minnesota alone. Affected areas include the Chippewa and Superior National Forests (NFs), but most of the disturbance lies within the Boundary Waters Canoe Area Wilderness (BWCAW) and Quetico Provincial Park. On the Superior NF and BWCAW, the amount of downed timber in terrestrial areas was truly extensive, on a scale unseen in recent times. High speed winds associated with the storm uprooted and snapped off trees in a swath 4-12 miles wide and 30 miles long. On the Chippewa NF, two of Minnesota's largest lakes, Cass and Winnibigoshish, had very high water levels at the time of the storm, which resulted in serious erosion of shoreline areas and structural damage to Knutson Dam. Trees also blew down in terrestrial areas of the Chippewa NF, but in small patches, totaling about 1,000 acres.

A Unique Research Opportunity

The especially large blowdown in and near the Boundary Waters Canoe Area Wilderness represents a rare opportunity to examine severe windstorm consequences that are unique in the history of forestry and ecological research for several reasons:

- ☆ Enormous areas of storm damage (in a wilderness) will not be subject to salvage logging, an exceedingly rare situation in the temperate zone after windthrow.
- ☆ The huge size of the disturbance may lead to unique effects, different from those generated by many small disturbances of equivalent area.
- ☆ The blowdown, and the following fires, will create gradients in disturbance severity, providing a rare opportunity to study forest and water responses.
- ☆ This disturbance took place in a near-boreal forest, which historically has never experienced massive windthrow as a major type of disturbance. Windthrow may push the system into a different set of successional trajectories than those previously generated by the historically dominant fire disturbances.
- ☆ Having occurred in a forest landscape type at the southern edge of its natural biome, this disturbance may be a model for forest change resulting from global warming. This floral and faunal transition zone depends upon alterations in types and/or frequencies of disturbance events.
- ☆ This disturbance is unique because it occurred in an extremely water-rich landscape. We don't know how drastically changing the patch structure within a landscape affects aquatic ecosystem structure and function; therefore, this storm gives us a unique opportunity to examine these processes across a gradient of disturbance intensities. For example, the disturbance provides an extraordinary opportunity to examine carbon flow between the upland and aquatic systems in a landscape context.

☆ The proposed work has important management implications. Carbon flux dynamics will influence, and provide a framework for better understanding, terrestrial-aquatic linkages, nutrient and contaminant dynamics, primary and secondary productivity, benthos, and fish. The unusual patch dynamics within landscapes will permit us to develop predictive models that incorporate wide ranges of disturbance intensities. It will also enable us to build explicit linkages to many other research areas and to incorporate human decisionmaking processes.

DISTURBANCE EFFECTS ON LAND-WATER-HUMAN INTERACTIONS: A MODEL FOR RESEARCH INTEGRATION

As a result of the massive blowdown and the accompanying efforts such as prescribed burning and salvage logging damage, nearly 500 thousand acres of pristine northern Minnesota terrestrial (ca. 400,000 acres) and aquatic (ca. 100,000 acres) boreal ecosystems have been (and will be) unequivocally and substantively changed from their pre-storm conditions. Many of these systems have been fully re-launched on new successional trajectories, and others have, at the very least, had their trajectories significantly modified. At the landscape level, there has been a vast restructuring of the boreal, patchwork mosaic of terrestrial communities. The impacts on aquatic systems and the underlying watersheds are as yet largely unknown. But, it is expected that significant changes have been triggered because the chemistry, thermal properties, hydrology, and physical properties of each pond, lake, stream, wetland, and watershed invariably represent the surrounding landscape. The expected changes in the hydrology of the windfall region are likely to have negative impacts on food quality in aquatic systems and result in decreased aquatic primary productivity.

The Research Goal

To better understand how ecological and social systems respond and adapt to sudden, catastrophic, large-scale environmental change and the resulting recovery and mitigation efforts in order to develop better long-term land-water management practices and better human services.

Two Fundamental Research Questions

Essentially two fundamental questions underpin the proposed research program: (1) What is the current condition or status of the system (including all of its attendant components) following the storm, and (2) How is the system going to change and recover in response to the storm damage, human mitigation efforts, and fire?

Describing the Post-Storm State of the System: A Comprehensive Multidisciplinary Effort

There is a compelling scientific and practical need to carefully and thoroughly describe what happened following the storm. Documenting the immediate, post-storm conditions of the natural and human systems is a crucial first research step and must proceed as soon as possible. It is straightforward, more or less descriptive science. It should be done by multi-disciplinary teams, using standardized protocols, at as many different levels or scales of ecological organization as can be afforded. It is the absolutely critical and essential first step needed to launch a storm research effort.

Studying Long-Term System Recovery: Employing the Land-Water Interaction Model

Secondly, investigating the full breadth of ecological and social consequences of these disturbances over the long term calls for a comprehensive, integrated research program. At the outset, it is important to formulate a research organizational framework that mimics, as much as possible, the functional, hierarchical constructs of nature and human social systems. For example, one such well-known construct, the ecosystem, is a naturally functioning entity comprised of self-sustaining populations of dozens of species of plants, animals, and microorganisms that coexist and interact while embedded in a particular abiotic and a biotic matrix. By their very nature, ecosystems require holistic, interdisciplinary team research in order to fully comprehend their workings and their dynamics. Terrestrial ecosystems are identified as land types (LTs) or land type phases (LTPs) according to the USDA Forest Service national framework for describing ecological units (McNab and Avers 1994). At the next higher hierarchical level, complex assemblages of ecosystems form landscapes, known in the ecological classification system as land type associations (LTAs). Still another very useful, but different natural organizational construct, the watershed, is a hierarchy of water drainage catchments. Each watershed level progressively contains more and more complex catchments made up of ever larger assemblages of terrestrial and aquatic ecosystems and landscapes. Like ecosystems, watersheds require a holistic, interdisciplinary research approach in order to fully comprehend their processes and dynamics. By choosing a system for study, one automatically also selects the spatial and temporal scales appropriate for that system.

This research program proposes to simultaneously address most of the essential ecosystem, landscape, and watershed processes and their component interactions across several scales of physical, biological, and social organization. It must, therefore, adopt an organizational structure that inherently facilitates the comprehensive work and, in so doing, integrates it to achieve real synthesis. The basic organizational model we propose for developing the research effort will be a hybrid model, which combines both the landscape-ecosystem and watershed models. Because the windstorm impacted a region (designated as the Border Lakes Subsection) nationally recognized for its rich and unique land-water interspersion, it is important to address how water quality, water quantity, and the diverse aquatic systems have been and will be affected by the terrestrial disturbances. The Border Lakes region is a complex landscape consisting of a myriad of lakes, wetlands, and streams. An estimated 62 fifth-level watersheds lie within the blowdown area. Therefore, use of the functional watershed model is absolutely essential in addressing many critical water issues. On the other hand, the watershed model is certainly not imperative for addressing many major ecological and social questions, but its use will not hinder the other needed research that can be accomplished through employment of the landscape-ecosystem part of the hybrid model. However, by explicitly including the hierarchical watershed model as one of the key organizing and underpinning research structures, the model allows all research disciplines to ask questions about the relationship of their research subjects (meteorology, vegetation, soils, humans,wildlife, insects, pathogens, etc.) not just to the functioning of impacted terrestrial and aquatic ecosystems, and landscapes, but also to the underlying watersheds.

Disturbance-Driven Research Framework: Disturbance Type and Severity

Overlaid upon the land-water interaction research model are three fundamental disturbance "treatments," which are the bases for much of the proposed research program. These exogenous inputs are part natural and part unnatural (derived from human mitigation): blowdown, salvage logging, and fire (prescribed or natural). Each of these treatments will consist of many different levels of severity and may be studied in a factorial arrangement. In the simplest factorial configuration (2x2x2), eight fundamental treatments would be studied across specially selected key ecosystems and watersheds.

These specially selected land-water interface study sites will be determined at an ad hoc workshop of all the principal investigators and the land managers before the research program is launched. A core group of study plots, sites, and watersheds will be adopted for many different investigators to work on, but each from their own disciplinary perspective. The purpose is to bring many different minds together to study the basic processes from different vantage points for more complete understanding of the processes. Studies that cannot be done on the common plots and sites because of their questions or their research subject scale needs, or for other reasons, will nevertheless be integrated with other studies to whatever degree possible.

Dynamics of System Recovery: Adopting a General Guiding Theoretical Response Model

Although a primary objective of this research program is to describe how different species, communities, ecosystems, and watersheds will respond to and recover from disturbances, it is even more important to learn something about the basic mechanisms of the recovery processes. To this end, it is crucial to form various hypotheses based on theoretical models that predict, *a priori*, the possible paths that the diverse systems may take. Those models that more often make correct predictions are ones that may better explain how nature works. One such model, the cusp-catastrophe model, has been widely used in physical, social, and ecological systems to understand dynamics and predict changes where the systems typically exhibit threshold effects. When a threshold is surpassed, the system can suddenly diverge to an alternate state. We propose that this particular model be offered as one of the main, general, theoretical heuristic models for understanding and predicting system dynamics, regardless of the particular system. It is a three-dimensional model, with the dependent variable complex (z) forming a response surface in relation to the state of the two key controlling variable complexes (x and y). Each system will require its own determination of the x, y, and z variable complexes.

Long-Term Data Archiving and Research Continuance

Establishing a long-term research program necessitates a firm plan for data archiving and an administrative structure for staying the course during the unfolding of long-term storm recovery processes. The North Central Station could be the archiving center under the auspices of the Station's Long-Term Data Archive, and the guiding organization for holding the research structure together as investigators come and go. Research coordination will continue through the currently established mechanism of Storm Research Coordinator and Storm Steering Committee (see charter). The Research Coordinator will be responsible for interfacing between scientists generating data and the data archive, and for encouraging research projects in priority areas identified in this plan or subsequent versions of it. The Storm Research Coordinator will be familiar with the long-term research projects and will document their research plans and their research plots so that they become public information for the larger scientific community.

About This Document

This document is the product of collaborative scientific review of issues and subsequent consensus-building to arrive at prioritized needs and recommendations for research.

Each of the following nine specific disciplinary research needs assessments is the result of issue papers developed by the focus group leader(s) and a team of experts in that disciplinary field. The issues papers were reviewed, critiqued, and revised through a research needs workshop process in which nearly 100 workshop attendees jointly developed a consensus list of research priorities.

We intend that this document be a resource for any researcher who seeks to propose research related to this disturbance event; for Federal and State agencies to use for research program planning; for land managers to prioritize storm recovery-related management activities; and for wilderness managers to prioritize research-related access to the wilderness areas affected.

DISCIPLINE-SPECIFIC RESEARCH NEEDS AND ISSUES ASSESSMENTS

Focus Group Leaders: Brian Potter, North Central Research Station; and Warren Heilman, North Central Research Station.

Focus Group Contributors: Lee Frelich, University of Minnesota; Chris Peterson, University of Georgia; Julie Winkler, Michigan State University; Karl Zeller, Rocky Mountain Research Station.

Theme 1. Altered Microclimate within and near Forest Patches and Large, Disturbed Areas

The Fourth of July blowdown dramatically altered the temperature, moisture, and airflow conditions (the microclimate) in large areas of northern Minnesota forests. The architecture of many areas changed from standing forest to fallen trees with snapped trunks and tip-up mounds. In addition, the blowdown substantially increased the amount of open forest edge within the region. Both these changes in architecture and texture influence the microclimate of the region. Subsequent logging, burning, and other treatments will alter these conditions yet again.

The altered microclimates these events create in terms of air and soil temperature, wind, humidity, and precipitation will influence many processes, from photosynthesis and respiration to regeneration and the survival of individual species of trees and herbs. In this water-dominated region, any microclimate changes will be manifest in the hydrology and will alter the fluxes of nutrients between air, soil, and water.

Previous research can help us understand the potential changes in microclimate. Studies of microclimate and hydrology after prescribed burns (Ahlgren and Ahlgren 1965, Ahlgren 1981) indicated that temperature and relative humidity extremes are greater in burned areas and that less rainfall is intercepted by vegetation and debris in burned areas. Other microclimate studies (Bates and Henry 1928, Chen *et al.* 1993, Carlson and Groot 1997) suggested that where salvage logging occurs, there will also be greater extremes of temperature, humidity, and wind.

However each of these research settings differs in major ways from the northeastern Minnesota blowdown. Prescribed burns in northeastern Minnesota rarely involve such high concentrations of fallen, coarse woody material, much of which will likely remain after a fire. Because of the fragile soils of the region and the selective destruction of the blowdown, any conclusions based on the microclimate of clearcuts must be applied with great caution. Finally and most importantly, no studies in the open literature examine the microclimate conditions found in and about the debris left by a blowdown of this nature.

The focus group identified two primary study themes. The importance of these themes was apparent in other research focal groups, where the impact of microclimate on such issues as nutrient cycling, hydrology, insect outbreaks, and fire behavior was discussed.

Aerial photography reveals that within the nearly half million acre blowdown, rings or strips of trees were left intact around many lakes. These buffer strips are significant because they may have unique microclimatic properties within the post-blowdown landscape—properties that will influence vegetation recovery and succession, wildlife use, and wildfire fuel conditions.

Outside of the buffer strips, four other basic forest conditions are of interest in the storm area: pristine forest; undamaged forest; unmanaged blowdown; and managed blowdown, i.e., those subjected to prescribed burning and/or salvage logging. Within each of these broad types, there are many variations due to soil, current or pre-storm vegetation, and position under fallen boles or fallen crowns. Each of these factors will have a markedly different effect on the conditions within a meter above or below the ground surface. To understand and predict the future hydrology and ecology of the storm area as a whole, we must understand the microclimate created by each of these conditions.

High Priority Research

1. Measure and compare temperature and humidity throughout the growing season in "buffer" strips of trees. The study would include a range of forest patch shapes and sizes. The expected outcome would be a much improved understanding of the role of buffer strips in recovery after disturbance.

2. Measure and compare the temperature, wind, precipitation, radiation, and humidity in the near-ground atmosphere in each of the four basic forest conditions.

Because of rapidly evolving changes in the microclimate and vegetation, this study must be implemented as soon as possible. Each of the replicated study sites would require equipment to monitor the following meteorological variables: temperature and precipitation at more than one height, relative humidity, wind, photosynthetically active radiation (PAR), and net radiation.

This study would provide invaluable information in its own right, but would also complement

ecological studies of hydrology, ecology, or entomology. One expected outcome is new understanding of how the debris and/or debris removal affects the microclimate experienced by regeneration. This understanding could be used to improve models (e.g., gap dynamics models) that attempt to predict the effects of disturbances and post-disturbance management options. Another outcome would be data conducive to creating an analytical model of rainfall interception by debris. Current models of forest interception (Gash 1979) do not apply when trees are horizontal, and a model that can be applied to such areas would be of great value to managers and scientists trying to understand the effects of this and future blowdowns.

Theme 2. Climatology of Damaging Wind Events for the Great Lakes and Northeastern United States

Although many of the natural resource management questions that have arisen as a result of the northern Minnesota blowdown deal with small-scale ecosystem issues, other questions arise about the characteristics and occurrence of extreme wind now and in the future. Damaging wind events present a significant hazard to commercial forestry and to natural forest environments. They are as common or more common than fire in many ecosystems of the Great Lakes region (Stearns 1949, Frelich and Lorimer 1991).

An understanding of the frequency and nature of such events, including their temporal and spatial variability, is essential for effective forest management. Damaging wind events are complex weather phenomena, because they occur at different spatial scales and are associated with a multitude of atmospheric circulation patterns. Some damaging wind events are fairly localized, whereas others can extend over hundreds of kilometers. In terms of circulation features, some events are associated with thunderstorm microbursts, others with tornadic thunderstorms, and still others with propagating storm complexes. The larger scale circulation patterns can range from strong upper-level troughs and well-defined cyclonic systems to upper-level ridges and weak frontal boundaries.

The development of an extreme wind-event climatology for the northern Great Lakes region would address many of these questions. A comprehensive climatological assessment of extreme wind events in the region would (1) set the context for the relative significance of extreme wind events as a disturbance agent in the northern Great Lakes region, (2) increase our understanding of the dynamics of extreme wind-event occurrence and the spatial impact on the landscape, (3) identify the larger scale atmospheric patterns and mechanisms that contribute to extreme wind events in the region, and (4) provide a means for assessing how the frequency of extreme wind events in the northern Great Lakes region might change in the future due to large-scale climate changes.

High Priority Research (in descending order):

1. Prepare a comprehensive climatology of damaging wind events using conventional surface observations.

2. Identify the synoptic- and subsynoptic-scale (500-5,000 km) circulation patterns associated with damaging wind events.

3. Integrate extreme wind-event climatological analyses into an electronic atmospheric disturbance climatology system.

4. Identify the interannual and decadal variability of damaging wind events.

5. Assess possible changes in damaging wind events in a perturbed climate.

Focus Group Leaders: Paul Tine', Minnesota Interagency Fire Center; Mark Finney, Intermountain Fire Science Laboratory.

Focus Group Contributors: Kevin Ryan, Intermountain Fire Science Laboratory; Doug McRae, Forestry Canada.

Theme 1. Forest Fuels Assessments

High Priority Research

1. Measure the decay rates of woody fuels by species and size class. This information will put into perspective the time scales for decay of the blowdown fuel complex compared with fire occurrence and expected fire frequencies.
2. Document annual decomposition and breakage (vs. decay) of woody fuels by species and size class. This indicates the location of woody fuel pieces on a vertical scale. In time and with snow compaction, woody fuel pieces, starting with smaller size classes, break off and fall to the forest floor. Incorporation of smaller size classes into the forest floor should occur first and reduce the spread potential.
3. Document fuel curing over time, especially related to large diameter fuel pieces; large amounts of cured large-diameter fuel will indicate a potential for a very intense fire (e.g., firestorm potential).
4. Measure the post-fire (or post-prescribed fire) recovery of fuels, in terms of fire behavior—how long do treatments last?

After wildfire or prescribed fire, the vegetation (and fuel complex) will change depending on characteristics of the fire and the pre-burn conditions. Eventually the vegetation/fuels will be capable of supporting fire spread. How this develops and what the characteristics of fire are at different post-fire time intervals will have bearing on the longevity of prescribed fire treatments that could be used to slow fire progress or change its behavior.

5. Determine how to predict fuel consumption. How well do slash equations from the Pacific Northwest and the Burnup model work? These models are the only tools available for predicting consumption associated with prescribed burning or wildfire conditions. Consumption is an important target parameter for prescriptions, and predicting it will be necessary for implementing a fuel management strategy for blowdown affected areas.

6. Determine how the blowdown fuel complexes change over time with no treatment (in-growth of shrubs, balsam fir, etc.). It is probably impractical to expect that more than 10-20 percent of the blowdown fuels can be treated through use of prescribed burning in the next decade or so. Thus, most of the area will either burn in wildfires or develop without fire. Knowing how the vegetation and dead fuels change without fire will help us manage fire in these areas and understand the ecological impacts of preventing fire from removing the blowdown fuels.

7. Measure fuel moisture changes in the blowdown area throughout the season compared to intact forest. The blowdown changes the physical arrangement of the fuels, increasing the exposure of these fuels to weather. As a result, the dead woody fuels and the remaining vegetation will be influenced more rapidly by precipitation and by drying. The more rapid changes in live and dead fuel moisture will likely be important to fire danger rating and to fire behavior.

8. Measure the spatial variability of fuels at various scales—using different resolution maps from different remote sensing technologies. Blowdown fuels are not uniform at all scales, but little information exists on the nature of this variability and on the scales at which these measures vary. This information will be important for spatial modeling of fires in the blowdown area as well as for locating treatments and treatment boundaries.

9. Document vegetation recovery (shrubs and herbaceous plants) and its mediating effects on woody fuel moisture and fire behavior (i.e., green-up effects) and seasonal trends in fire behavior (i.e., summer vs. spring conditions).

10. Regarding fuel consumption, consider fuel models from the Canadian mass fire study and dead cured balsam fir slash models.

Theme 2. Fire Behavior

High Priority Research

1. Determine the criteria for go/no go for prescribed fire in the blowdown fuels; e.g., when is it OK to burn without fire lines? The large scale of the Boundary Waters blowdown and the inaccessibility of the area for traditional ground-based firefighting tactics preclude the extensive construction of firelines to delimit prescribed burn areas. Thus, "lineless" burning will be required under a set of prescription conditions that permit a reasonable level of control by virtue of the weather and fuel moisture conditions under which the burning is

accomplished (and natural barriers like lakes). This probably means that late fall is the only time that this burning can safely be done, but an analysis of weather conditions and research into fire behavior under various conditions would help pinpoint the appropriate timing.

2. Measure fire growth rates and acceleration rates from point-source ignitions in the blowdown fuels. Fires igniting from point-sources like lightning or a cigarette require a period of time before they are capable of reaching their potential spread rates and behavior. The blowdown fuels probably require 1/2 to 1 hour to reach calculated spread rates and intensities for a given set of environmental conditions, but this is not well known. The acceleration rate of these fires has bearing on the response time allowed for suppression and for buildup of spot fires ahead of a main fire front.

3. Determine how to estimate spotting distances from blowdown fuels; can we use Albini's pile model? Spotting is probably the most difficult behavior to address during suppression efforts because of the potentially long distances (miles) that embers can travel and ignite new fires. Spotting over lakes and barriers is common in the Boundary Waters, and its prediction or estimation will be critical to conducting prescribed fire treatments and to predicting wildfire behavior in blowdown fuels.

4. Develop proper prescribed fire ignition procedures to prevent unusual or unexpected safety problems (e.g., firestorms).

Theme 3. Fire Effects/Ecology

High Priority Research

1. Investigate effects on forest floor moisture and consumption potential; do more sun-exposed sites lead to more consumption potential? This may lead into answering questions on post-fire seedbed quality and successional patterns.

2. Develop an understanding of the spatial distribution and variability of desired seed trees (residual seed trees still standing) over the blowdown area. This is linked to expected post-fire successional trends. We need to understand the potential to restore early successional or intolerant species back onto the sites (e.g., jack pine). Results can also be used to prioritize areas to burn with a low-intensity prescribed fire to protect parent seed trees (e.g., red pine, white pine) before a high-intensity wildfire occurs that could kill these trees and probably convert the site into a mixed wood site.

Focus Group Leaders: D.W. Gilmore, University of Minnesota; and J.C. Zasada, North Central Research Station.

Focus Group Contributors: Brian Palik, Terry Strong, and Lucy Tyrrell, North Central Research Station; Janet Green, University of Minnesota—Duluth; Alan Haney, University of Wisconsin—Stevens Point; Robert Pajala and Kurt Rusterholz, Minnesota Department of Natural Resources; Sara Webb, Drew University.

Theme 1. Effects of Alternative Management Strategies on Forest Successional Pathways

Windstorm-damaged forests are usually salvaged to reduce forest fire hazard, reduce insect and disease problems, and use downed and merchantable trees for forest products. Disturbances such as windstorms, snow and ice damage, wildfires, and insect epidemics have always affected northern forests at varying scales and frequencies and are a part of the evolutionary and ecological context of these forests. Following these natural disturbances and human management practices, how do such forests typically recover? It is important to study how the successional patterns in areas undergoing various salvage and fuel reduction treatments, singularly or in combination, differ from the natural forest community successional patterns that occur in untreated areas.

The Federal environmental impact assessment process requires that a "no management" alternative be evaluated in the context of any proposed human management activities. Many retrospective studies have been done on the effects of various types of disturbances on forest stand development in the BWCAW and Itasca State Park. However, no long-term studies have been established in Minnesota to quantify the effects of alternative silvicultural treatments (e.g., site preparation, planting, direct seeding, and vegetation management) on stand development patterns in conjunction with severe wind disturbances in northern Minnesota.

The Silvics Focus Group spent considerable time discussing the selection of management treatments and the stratification variables to use in an experimental design. Suggestions included: forest cover type, age class, soil/land form, land type phase, category of blowdown intensity, protocol for measuring coarse woody debris, fire intensity, previous disturbance history, timing of post-storm treatments, regeneration objectives, regeneration response to various treatments (site prep/planting), and forest products (fiber, aesthetics, alternative forest products).

High Priority Research

1. Measure baseline ecosystem data and monitor forest vegetation change in riparian zones. Such data are invaluable in understanding the riparian forest communities and their crucial links to the state of adjoining fresh water systems.

2. Measure baseline ecosystem data and monitor successional changes in diverse, non-riparian ecosystems following storm damage and several alternative silvicultural practices (harvest, fire, natural and artificial regeneration, site preparation, competition control, etc.) to describe and to predict successional trajectories.

3. Monitor survival and growth of undamaged and partially damaged trees and associated plant species in areas affected by the storm alone and in areas affected by the storm and subsequent fuels and salvage treatments.

Theme 2. Silvicultural Methods for Minimizing Pest Impacts and Increasing Forest Resiliency to Stress

Forest insects and diseases can sometimes be devastating in boreal and north temperate forests. For example, balsam fir and white spruce after leaving the pole stage are highly prone to periodic, catastrophic outbreaks of the indigenous spruce budworm. The outbreaks typically cause severe mortality in near-mature and mature balsam forests, thereby increasing the probability of fire. Spruce forests, although just as susceptible to budworm outbreaks, are not prone to high mortality because they are much more capable of tolerating severe defoliation. Likewise, tamarack is highly prone to outbreaks of the larch sawfly and the larch casebearer, two introduced defoliators. On some sites and typically after drought, these outbreaks can trigger severe overstory tree mortality, causing stands to convert to largely black spruce. Can these three tree species be managed in novel ways to substantially lower the probability of insect outbreaks and subsequent wave-like tree mortality? Other tree species such as white pine are currently much less abundant in northern Minnesota forests than before European settlement. Heavy harvesting, abundant deer populations, the invasion of the exotic white pine blister rust and the introduced pine sawfly defoliator, and less frequent wildfires may have all worked together to suppress white pine abundance at much lower than historical levels.

High Priority Research

1. Determine how to manage for longer lived conifers such as white pine and red pine. For white pine, it is important to know how to (a) increase white pine natural regeneration where appropriate, (b) artificially regenerate white pine, and (c) minimize the impacts of white pine blister rust, introduced pine sawfly, and white-tailed deer on the survival and growth of trees. For red pine, more information is needed on the best methods for natural and artificial regeneration and the conditions under which each is most appropriate.

2. Determine how to orchestrate landscape patterns of white spruce and balsam fir to minimize the impact of spruce budworm on their growth and survival.

3. Determine the most important insects and diseases affecting survival and growth of trees that survived the storm.

Miscellaneous Issues

Focus group discussions stressed the necessity of a common data collection protocol for the integration and synthesis of data with the other research groups on disturbance ecology, watershed management, wildlife, fire ecology, and entomology and pathology. The fundamental distinction between silviculture and these other focus group disciplines is that silviculture is the art and science of managing a forest to achieve

landowner objectives. In other words, by definition, silviculture implies that deliberate human-caused actions be imposed on a forest ecosystem. Indeed, except for disturbance ecology, silviculture prescriptions commonly take into account the issues/concerns of all the focus groups—watershed, wildlife, fire, landowner concerns/desires, and insect and diseases. Components of all research focus groups can be incorporated into the proposed silvicultural research design for the Gunflint Corridor. The disturbance ecology research group could facilitate the collection of data for the untreated or unmanaged plots where natural succession would develop in the absence of human intervention. Funding for baseline data collection should be shared among all focus groups.

Focus Group Leaders: Sandy Verry and Dale Nichols, North Central Research Station.

Focus Group Contributors: Dave Grigal, University of Minnesota; Bob Berrisford, Superior National Forest; Brenda Glenn, Chantel Cook, and Nancy Salminen, Chippewa National Forest; Nolan Baratono and Bruce Wilson, Minnesota Pollution Control Agency.

Theme 1. Impacts of Road Crossings on Streams under Blowdown and Logging Disturbance Regimes

Within forested regions, road crossings are a major disturbance to stream systems. Fine sand from unpaved roads can fill pools and cover riffles as much as a mile downstream and remain in the channel for many years. Undersized culverts can accelerate water velocity causing channel erosion downstream (Verry 2000). Large woody debris is an important component of streams, influencing the velocity

of water flow and the retention of organic and inorganic sediments, and providing habitat for aquatic organisms. Severe wind storms can add large amounts of woody debris to streams that can shape stream habitat character for decades or centuries. Woody debris can also block culverts and bridge openings, leading to road washouts and additional erosion and sedimentation of streams. A stream system in North Carolina was found to contain 76 pieces of wood per kilometer before Hurricane Hugo and 186 pieces per kilometer after the hurricane. However, in that particular case, the riparian forest was less than 60 years old and most of the input was small trees and branches subject to rapid decay and movement out of the channel, so the benefits to stream habitat may be relatively short-lived (Dolloff and Webster 2000).

While road crossings may seem an obtuse measurement site for evaluating blowdown and fire impacts, the streams above and below these crossings are ideal places to evaluate stream condition in blowdown, fire, and logging disturbance regimes. Contrasting conditions of normal logging operations west of the blowdown area outside the BWCAW (the Little Fork-Vermilion Uplands Subsection 212Ma) with blowdown conditions along the Gunflint Trail (the Border Lakes Subsection 212La) offers an opportunity to evaluate the relative impact of road crossings on physical stream condition in very different disturbance and geologic regimes. In this type of study, stream condition is evaluated against modal values of stream width and depth (corrected for drainage area), and the depth of pools and riffles for a given stream type (Verry 2000, Rosgen 1996). Large woody debris—a hazard to crossings, but usually a positive addition to stream habitat—would be measured in stream sections above and below crossings.

High Priority Research

1. Evaluate deviations from modal stream values in 20-30 sites in each subsection of the Superior National Forest in St. Louis and Lake Counties. Specific parameters would be tested (t-tests) for differences between subsections and for deviations from modal values. Within this study, Gunflint Trail blowdown sites would be evaluated before the Pelican to Namakan Lake logging sites.

Lower Priority Research

2. Evaluate crossings on Menominee Nation Streams. A third group of crossings could be evaluated on the Menominee Nation streams in Wisconsin to compare blowdown and early succession logging with logging and transportation systems used in sustained old-growth forest conditions.

3. Evaluate crossings in the Chippewa National Forest/Itasca County. The Ecology and Management of Riparian and Aquatic Ecosystems unit of the North Central Research Station in Grand Rapids, Minnesota, is evaluating road crossings in the Rice River watershed in Itasca County and in the Chippewa NF as part of a physical watershed assessment study. This study will provide a fourth comparison in a glacial till and in glacial lakebed geology.

Theme 2. Recruitment of Large Woody Debris (LWD) to Lakes with and without Blowdown

Large woody debris along the shores of lakes protects shorelines from wave action, traps sediments, and provides riparian and aquatic habitat complexity. Fish species richness is directly related to habitat complexity, and simplifying habitat has a negative impact on fish (Bolgrien and Kratz 2000). Recruitment of large woody debris into lakes is often associated with major windstorms and subsequent high water needed to carry material into the water. This may have a beneficial impact on fish abundance in lakes having large additions of wood. Around the shoreline of some of the lakes in areas of severe blowdown on the Superior NF, a ribbon of trees remained standing after the storm, while on other lakes such trees were not spared. Whether these residual trees will be subject to eventual windthrow remains to be seen. Knowledge of such factors as topography, geology, and soils in blowndown and unaffected lake riparian areas may be helpful in predicting where trees may or may not blow down in the future.

High Priority Research

1. Measure the amount and distribution of LWD within the littoral zones of blowdown and unaffected lakes.

2. Measure fish community composition and abundance in lakes with large amounts of blowdown LWD and in lakes without blowdown recruitment of LWD.

Lower Priority Research

3. Measure and compare topography, geology, soils, and stand structure and composition in lake riparian areas subject to blowdown and not subject to blowdown, within areas of severe blowdown damage.

4. Conduct long-term monitoring of windthrow of still-standing lake riparian trees in areas of severe blowdown and compare to windthrow rate of lake riparian trees outside of the blowdown area.

Theme 3. Water Quality Changes Following Blowdown, Salvage Operations, Fire, and Firefighting Operations

Large fires or blowdown/fire disturbances always raise concerns about impacts on water quality. In a review of fire impacts on aquatic habitat, Gresswell (1999) summarized a number of studies in North America, including the work of Wright and Grigal in separate studies of the Little Sioux Fire (spring burn) in the BWCAW, and concluded that fire only temporarily increases the concentration of phosphorous, nitrogen, calcium, magnesium, and potassium in lake or stream water. Additionally, internal Superior NF memos with data from the Roy Lake Fires (intense summer burns), and very detailed fire studies at the Experimental Lakes Area in Ontario (about 200 miles north of the BWCAW) support this conclusion. The largest increases are associated with windstorms after the fire that blow ash into the lakes. All these studies show that effects are temporary and that fire does not lead to actual lake eutrophication with visible algae blooms and a decrease in

dissolved oxygen in the hypolimnion. Nevertheless, impacts on water quality are a high visibility issue with most people, and agencies are expected to monitor any impacts. In discussions with Nolan Baratono (Minnesota Pollution Control Agency (MPCA)—Rainy River Basin Coordinator) and Bob Berrisford (Hydrologist—Superior NF) after the St. Paul workshop, we learned that MPCA would like to pursue water quality studies in cooperation with the Minnesota DNR and the Forest Service. Because of the size of the blowdown, it is not practical to pre-sample lakes in hopes of catching those that might eventually have fires in their respective basins. Thus, we focused on the following study objectives:

High Priority Research

1. Re-sample water quality in lakes of the Eastern Lake Survey in selected heavy blowdown areas and in areas with little or no blowdown. In 1984, 177 lakes in northeastern Minnesota were sampled for chemical analysis as part of the U.S. EPA's Eastern Lake Survey (ELS) (Kanciruk *et al.* 1986). About 90 of these lakes are located in the general blowdown area, and about 25 are in the heavy blowdown area between Basswood Lake and Seagull Lake. The ELS analyses on these lakes provide pre-blowdown and pre-fire background water quality data. We will use these as a basis of evaluating impacts of blowdown alone. This comparison will extend the ELS data in a time trend that may reveal water quality changes related to climate change or changes in atmospheric deposition as well as blowdown effects.

2. Compare water quality in a set of lakes outside the BWCAW that did have salvage operations in their riparian shoreland and another set of lakes outside the BWCAW that did not have salvage operations. Size, volume, flushing rates of lakes, and the geology in the two "treatment" groups would also have to be evaluated to take these factors into account.

3. After large fires, compare water quality in lakes having basins with similar geology (all volcanic or all granitic) with and without fire. Lakes experiencing fire over their watersheds can be sampled after fires occur, but due care in selecting lakes on similar geology is needed to reduce variation from rock type alone. Evaluation of this data set can be done with an ANOVA, but deductive reasoning that includes an inventory of watershed condition must also be a part of the interpretation. It is probably not practical to pre-sample lakes in the hope of catching those that might eventually have fires in their basins. However, if fires do happen to occur adjacent to ELS lakes, these background data can be used to good advantage.

Lower Priority Research

4. Test if blowdown and fire increase the rate of mercury methylation. Water table fluctuation in peatlands surrounding lakes has been associated with methyl mercury at studies in the Experimental Lakes Area east of Kenora, Ontario. Thus, changes in the water balance of the BWCAW may cause changes in the rate of mercury methylation. A study to identify the sites where mercury methylation is strongest in the landscape is currently underway at and near the Marcell Experimental Forest in Itasca County, Minnesota. It is an EPA-funded, 3-year study to investigate upland mineral soils, acid wetland soils, neutral wetland soils, streams, and lakes for the rate of mercury methylation occurring there. Field studies will be done in September of 2002. Scientists from the soils and ecology departments at the University of Minnesota, the MPCA, the Science Museum

of Minnesota—Saint Croix Watershed Unit, and the North Central Research Station are involved with this. When differences in site mercury methylation are confirmed in this study, the results could be used to select landscape sites and design fish community sampling in blowdown and burned areas of the BWCAW well after fires occur.

5. Measure changes in fish taste resulting from fire. It is common knowledge among the Inuit Nations in Canada that large fires adjacent to lakes cause fish to taste like burned fish soup. The flavor apparently derives from the fish ingesting ash blowing into lakes or just from absorpbing the ash into their flesh when there are high concentrations in the lake water. Those of us less accustomed to frequent and long-lasting peat fires adjacent to the lakes we use might want to know what to expect.

Theme 4. Water Visibility Degradation in the BWCAW

If visibility is currently measured at the Fernberg Lake site, then continued monitoring of visibility during and following fire could be compared to similar measurements at Voyageurs National Park. The Superior NF's evaluation of the Roy Lake fire indicated that blowing ash was the cause of reduced visibility and contributed to phosphorous concentration peaks in lakes. If visibility measurements are not already ongoing, they could be established and compared between the BWCAW and Voyageurs.

High Priority Research

1. Monitor visibility in BWCAW and Voyageurs Lakes on a continuing basis for 2 to 3 years.

Lower Priority Research

2. Monitor visibility in other lakes in the Lake States.

Theme 5. Soil Quality Changes Following Blowdown, Salvage Operations, Fire, and Firefighting Operations

Good logging practices will minimize soil compaction and retain sufficient soil carbon, calcium, magnesium, nitrogen, phosphorous, and potassium to regrow a new forest to at least the same level of biomass produced previously. This is desirable for blowdown salvage logging as well as for the harvest of standing live trees. Differences in the number of living trees on sites before logging can result in significant differences in logging impacts on the sites. Blowdown areas are likely to have high soil moisture levels before harvesting equipment enters the area because the trees are dead and not transpiring water. In salvage logging, it may be difficult to avoid tracking on wetter soils and thus the potential for soil compaction is increased. It is likely that salvage logging may be intermediate between clearcut logging and fire origin stands without previous logging in terms of the amount of LWD that occupies the site during a rotation period (interpreted from Duvall and Grigal 1999).

High Priority Research

1. Extend existing LWD, regeneration, and soil strength studies of the North Central Research Station's Silviculture unit in Grand Rapids to include similar sites in riparian shorelands. These sites should correspond to the suggested water quality study sites for salvage-logged and not-salvage-logged sites in theme 3. Sites should also be included

where prescribed fires for fuel reduction are planned. While soil nutrient levels, organic matter, porosity, bulk density or soil strength, soil erosion, and soil water levels are possible topics of study, LWD (snags and on the ground wood), soil strength, and regeneration should be the focus where funding is limited.

Lower Priority Research

2. Measure soil nutrients, organic matter, soil moisture on salvage-logged, not salvage-logged, and burned sites (basically an expansion of item 1 to include additional measurements).

Theme 6. Beaver Pond Changes Following Blowdown and Fire

After the Fourth of July storm, the Minnesota DNR-Forest Resources unit in Grand Rapids immediately prepared regional GIS maps of the blowdown area and made these available on the web. We presume the DNR will do the same after major fires occur. Forest regeneration patterns that yield larger areas of aspen suckers will give rise to the construction of more beaver dams when this material reaches 2 to 5 inches in diameter. As a result, the ease or difficulty of portage or water passage will change. The change may be significant enough to change portage routes or even diminish some campground areas that flood. Severe fires that burn to bedrock may exclude forests.

Higher Priority Research

1. Prepare regional GIS maps after major fires (to be done by Minnesota DNR-Forest Resources).

2. Repeat the GIS mapping at 5-year intervals.

3. Evaluate beaver pond occurrence and loss at 5-year intervals using GIS landscape trend analyses.

Theme 7. Storm-Caused Shoreline Erosion on Lakes, Reservoirs, and Their Rivers

Much of the storm damage on the Chippewa National Forest in Itasca, Cass, and Beltrami Counties was accelerated bank erosion on both the windward and leeward side of lakes. This included 600 feet of bank near the West Winnie Summer Homes, 4,400 feet near the South High Banks Summer Homes, and 2,000 feet near homes on Star Island in Cass Lake. Additional beach and bank erosion occurred at the Cass Lake and Wanaki Campgrounds in the Norway Beach Area on Cass Lake. A mile and a half of severe bank erosion resulted from this storm. While the spring of 2000 seems headed toward drought conditions, wet periods to follow will yield unusually high water levels in the BWCAW as well and may cause limited bank erosion in lakes that have high glacial till terraces adjacent to the water.

Although 60 to 70 mile an hour winds on July 4, 1999, caused the banks to erode, these banks were predisposed to accelerated erosion by high water levels on the Winnie, Leech, and Cass Lake reservoirs. Note that at high water levels, Winnie Dam controls the water level in Cass Lake too. The high water levels in the summer of 1999 were caused by high seasonal rainfall and by the operation schedules of dam gates on the reservoirs. Reservoir operation schedules have caused accelerated erosion between storms on nearly 100 miles of the upper Mississippi River for decades. Erosion sites are located between Winnie Dam and several miles south of the Highway 200 crossing near Jacobson, Minnesota.

High Priority Research

1. Re-examine the seasonal schedule for reservoir water elevations and river flow targets throughout the upper Mississippi system above Brainerd, Minnesota (confluence with the Crow Wing River). This should be a cooperative effort with the U.S. Army Corps of Engineers, the Upper Mississippi Headwaters Board, counties, Native Nations, and the Minnesota DNR.

2. Consider deploying in-reservoir (in-lake) reefs as synergistic additions to traditional bank riprap and bioengineering bank stabilization programs.

Focus Group Leader: Jim Perry, University of Minnesota.

Focus Group Contributors: Pat Brezonik, Jim Cotner, Sarah Hobie, Lucinda Johnson, Ray Newman, Carl Richards, Heinz Stefan, Bob Sterner, Deborah Swackhamer, Bruce Vondracek, all from the University of Minnesota.

Theme 1. Landscape Structure and Function

The relationship between landscapes and lakes is hierarchical: geomorphology and geology affect hydrologic processes, and thus movement of solutes; hydrology and solutes affect productivity. Geology affects lake chemistry and biota through the delivery of nutrients and other ions released from weathering rocks. Most notable of the nutrients released from the underlying geology is phosphorus, which is a limiting nutrient in many aquatic ecosystems. Morphological characteristics of the landscape affect the rates of transfer and processing of solutes in surface water. Thus, water chemistry is greatly affected by the underlying geology of the landscape surrounding the lake as a consequence of different hydrologic flowpaths.

Water chemistry has a strong and well-understood influence on species composition in lakes. The availability of appropriate forms of carbon and nutrients (e.g., phosphorus and nitrogen) controls lake productivity, pH, and conductivity and can affect the community composition by eliminating less tolerant species of both animals and plants. Vegetation affects aquatic habitats

downstream by processing, and in some cases removing, nutrients and ions released from the weathering of rocks. This endogenous control is known to be important in maintaining stream water quality and is increasingly being applied to stream riparian management (Osborne and Kovacic 1993).

Spatial relationships between a lake and particular landscape elements (i.e., vegetation patches, geologic landforms) will mediate the strength and nature of the aquatic-terrestrial linkages, but the relevant spatial scale for such interactions is not clearly understood. Although the importance of geomorphology and vegetative characteristics in a drainage basin to lakes has been established, lakes located farther downstream of a particular geologic formation or vegetative patch will be less affected by that landscape element as a result of dilution and abiotic and biotic nutrient processing. Because the effects of drastically changing the patch structure within a landscape on aquatic ecosystem structure and function are unknown, the Fourth of July storm presents a unique opportunity to examine these processes across a gradient of disturbance intensities.

The wilderness designation of the BWCAW, along with the remoteness of the affected area, puts special constraints on monitoring and research in this area. As a result, we must be prepared to use remotely gathered data to the extent possible. Currently, contemporary LandSat satellite imagery at a scale of approximately 30-m resolution is available with seven spectral bands that can be used alone or in combination to characterize a number of both upland and aquatic features. This imagery has been used in conjunction with phenological information to map terrestrial land cover classes to the species and species-complex level (Wolter *et al.* 1995). The same type of imagery is currently being used by land management agencies across the forested regions of Minnesota. Within lakes, temperature, turbidity, chlorophyll, and possibly dissolved organic carbon (DOC) concentrations can be quantified, along with the extent of macrophyte growth. In addition, newer high-resolution imagery (e.g., IKONOS) at the scale of between 1- and 5-m resolution is currently available (albeit at a high cost) and can be implemented in areas where more detailed data are necessary. We anticipate that newer remote sensing products, including airborne hyperspectral imagery, can be calibrated to quantify features of interest to the aquatic ecologists. Variables such as biomass of woody debris, both above ground and under water, could be analyzed using such a tool. Until those tools become more widely available, traditional photogrammetric methods (i.e., air photo interpretation) are likely to be the most useful tools for quantifying disturbance intensity and features like standing stocks of woody debris. Where possible, data loggers and sensors should be deployed to collect *in situ* data (e.g., temperature, PAR, UV-B, chlorophyll) within the water column of lakes, streams, and wetlands across the range of landscape conditions and the disturbance gradient. Sidescan sonar may be useful on a lake-by-lake basis for quantifying wood on the bottom of lakes, along with information on bottom sediments and topography.

High Priority Research

1. Develop a spatially explicit model of the distribution of aquatic and riparian systems within and adjacent to the blowdown area.

   Existing and newly developed spatial data will be used to characterize the landscape context (patch structure) of aquatic ecosystems and riparian areas across the blowdown and surrounding area. In addition to existing

land cover data, high-resolution imagery and/or photography will be used to map lakes and streams and their riparian fringes across a gradient of disturbance intensities at a high level of classification resolution. Particular emphasis will be placed on mapping riparian areas. Since internal processes and communities differ among lakes along a hydrologic flowpath, we will select systems ranging from perched (rain-fed) to well-connected systems (ground- and surface-water-fed) for intensive studies. In addition to land cover maps, other spatial data including topography, soils, and surficial and bedrock geology will be acquired for the blowdown region.

Spatial data will be used in conjunction with land cover data to parameterize a landscape model (probably LANDIS) to predict successional pathways as the system recovers from the primary disturbance (Mladenoff and He 1999). One of the products of this effort will be a map of vegetation cover types in time steps, as the vegetation responds to disturbances such as wind, fire, and climate change. This modeling effort will be used as the overarching framework within which the aquatic ecologists will conduct their more intensive data gathering efforts. We will collaborate with scientists in other issue areas to develop and parameterize this model.

2. Develop or calibrate a hydrologic model that will link LANDIS to flows of water and associated materials among patches.

   Vegetation cover, elevation, and soil maps will be used to parameterize a hydrologic model to predict flow as well as sediment, carbon, and nutrient inputs to streams and lakes. Models such as SWAT and ADAPT are appropriate for predicting the effects of land use on water quality and have been used successfully by several researchers in agricultural systems (SWAT model: Srinivasan and Arnold 1994, Desmond *et al.* 1996, ADAPT model: D. Mulla, Department of Soil, Water and Climate, University of Minnesota, personal communication). These models potentially could provide an appropriate framework for this study. SWAT is intended to predict the effect of management decisions on water, sediment, nutrient, and pesticide yields on large, ungauged river basins. We will incorporate the suggestions of Manguerra and Engel (1998) for parameter calibration. Spatial data could be combined within Arc/INFO GIS to develop smaller units in relation to subdrainage to determine water, sediment, and nutrient delivery.

Theme 2. Carbon Cycling Within and Among Linked Aquatic Ecosystems in the Landscape

High Priority Research

1. Develop a detailed model predicting coarse woody debris input to streams and lakes, based on and modified from that of Meleason *et al.* 2000.

   Coarse woody debris (CWD) is an important morphological structure in lakes and streams (Gregory *et al.* 1991). As a large structural element, it alters the channel morphology and flow regime in rivers and provides critical habitat for fish, invertebrates, algae, and a large array of microorganisms. The biofilm that becomes established on CWD is an important food source for fish and invertebrates, and it contributes to the carbon pool both directly through primary production and indirectly through breakdown of the wood.

We will map riparian trees across a gradient of blowdown conditions and will tag standing trees, snags, and downed trees. Landscape data including topography and soils will be used to predict areas vulnerable to future windthrow. Logs will be censused periodically thereafter. Woody debris transport and retention dynamics will be measured at "intensive" study sites.

2. Assess the role that coarse woody debris in lakes and streams plays in driving microbial, primary, and secondary production; trophic interactions; habitat heterogeneity; and nutrient and carbon cycling.

   The role of CWD in streams (particularly in the Pacific Northwest) is fairly well understood (e.g., Harmon *et al.* 1986, Gurnell *et al.* 1995); however, relatively little is known of its role in lakes and wetlands, particularly with respect to nutrient cycling. We will link data collected in other themes and other research areas to our models, allowing us to test the relationships between large wood dynamics and structure and function of discrete aquatic ecosystems within and adjacent to the blowdown area.

3. Quantify the interaction between landscape context and disturbance intensity on organic matter delivery, retention, and decomposition in streams and lakes.

   Within the blowdown area, the riparian vegetation of some lakes was completely unaffected by windthrow, while riparian strips of nearby lakes were completely destroyed. Some of these standing trees are vulnerable to windthrow. Depending on the hydrologic conditions of the receiving waters, newly recruited coarse woody debris either will remain immobile or will be transported through wave action or streamflow. These newly recruited logs provide important habitat for fish, invertebrates, and biofilm-forming microorganisms. Nutrients and dissolved organic carbon are leached from submerged logs through time. Decomposing logs also provide fine and coarse particulate organic matter. Physical effects on the receiving waters will vary depending on the hydrologic regime, with large changes in channel morphology expected in streams and more subtle changes expected in lakes and wetlands.

   Organic matter processing/cycling will be examined as a function of the gradient of disturbances and in the context of landscape position along the hydrologic gradient.

Theme 3. Physical Changes in Lakes, Streams, and Wetlands

Physical conditions provide the framework within which chemical and biological processes in lakes, streams, and wetlands function. With information on runoff rates and runoff quality being collected by other research area groups, we will focus on how instream and inlake processes and parameters are changed by the blowdown. Light is one such parameter, water temperature is another, and turbidity/suspended sediment is a third. Water stages and flow velocities will be needed but may be measured by researchers in other groups. Coordination will be necessary. Light and water temperature are controlling factors for primary productivity, grazing and predation, and fish growth and survival to name just three crucial aquatic processes. The blowdown provides a unique opportunity to study these physical parameters under both open water and ice cover conditions and to relate them to the severity of the blowdown.

High Priority Research

1. Determine the role of riparian vegetation on the temperature regime of streams and small lakes.

   Removal of riparian trees is known to raise stream temperature substantially in summer. However, the effect is difficult to quantify (Sinokrot and Stefan 1993). Dynamic stream temperature recording in carefully selected stream reaches, impacted differently by the blowdown, can provide the extensive data necessary to quantify *a priori*, and not by backwards calibration, the effect of shading on the stream temperature regime at different time scales. Similarly, the partial shading of small ponds affects the heating rates of these water bodies. The temperature changes inflicted by loss of riparian shading can be expected to be large enough to substantially affect fish habitat. The outcome will be an overall assessment of blowdown effects on stream temperatures in the affected area. The potential impact on coldwater fish habitat can also be considered.

   The Stream Network Temperature Model (SNTEMP) was developed by Theurer *et al.* (1984) and Bartholow (1989) to evaluate the role of riparian vegetation in moderating stream temperatures. It will be useful in predicting temperature differences between blowdown areas and un-impacted areas. The model is based on three components that collectively affect stream temperature: meteorology, hydrology, and stream geometry. Meteorological influences include air temperature, relative humidity, wind speed, percent possible sun, and ground-level solar radiation. Hydrological measures include discharge and initial water temperature. Stream geometry consists of the network layout, site elevations, stream widths, roughness, and shade estimates. Net heat flux is calculated as the net sum of heat in the form of solar radiation, convection, conduction, evaporation, shading, streambed friction, and back radiation from the water.

2. Develop a relationship between riparian shading, light, and primary productivity in streams.

   Shading affects not only the heat budget of streams substantially, but also the availability of PAR and hence primary productivity. Measurements of PAR in streams impacted differently by the blowdown will allow us to quantify the relationship with shading, and from there with primary productivity and its contribution to total carbon in a stream. This research will complement the work on runoff and nutrient conditions in streams. Field measurements in addition to PAR will be 24-hour dissolved oxygen (i.e., diel DO) measurements to determine primary productivity. Solar radiation data from a weather station will provide the reference for atmospheric light input. The goal is to quantify the effect of shading on stream primary productivity for application to riparian vegetation management.

   Litterfall can be an important component of the nutrient cycle of a small lake. France and Peters (1995) examined litter input from a healthy riparian system and estimated that allochthonous input could contribute up to 10 percent of total carbon and 15 percent of total phosphorous to an oligotrophic lake. A model subsequently predicted that the removal of shoreline trees would decrease primary production, which in turn would reduce biomass at higher trophic levels. In addition, plankton respiration was predicted to be reduced more than production, shifting the lake community from allotrophy to autotrophy. A subsequent inquiry of litter differences between clearcut and forested

lake margins confirmed a reduced potential input of carbon and phosphorus, and it predicted 90 years would be required to achieve a new nutrient balance after clearcutting (France *et al.* 1996).

Not only is litter an important component of a lake nutrient cycle, but it also affects riparian erosion and sediment input. An examination of riparian stands around 10 Ontario lakes found that those clearcut 4 to 10 years earlier produced 60 percent of the litter of nearby uncut forests (France 1997a,b). Four different representations of ground litter were replicated in the lab and subjected to artificial rainfall at four different slopes. A consistent result was that litter characteristic of mature forests protected soil surface from erosion better than clearcut conditions (France 1997a,b). A continuation of this study found a significant difference between nearshore riparian litter and that in upslope regions (France *et al.* 1998). Low rate of litter production and the coniferous character of nearshore forest imply a reduced ability to buffer lakes from sediment originating in adjacent clearcuts (France *et al.* 1998).

3. Determine how shoreline vegetation affects lake temperature stratification.

   Wind action on lakes and streams affects their heat losses by evaporation and convection. As these losses are increased by removal of riparian vegetation during a blowdown, heat budgets and hence water temperatures are affected. Characterizing the wind accessibility of lakes, especially small ones, under different degrees of sheltering is possible in the BWCAW because of the large number and variety of lakes present. Wind access also affects the summer stratification found in many lakes. Lake surface area and maximum lake depth have been combined in a lake geometry ratio (Gorham and Boyce 1989) to characterize whether lakes are likely to become seasonally stratified or polymictic, which makes a large difference (e.g., for dissolved oxygen, water temperatures near the lake bottom, and consequently, fish habitat). Wind sheltering by riparian trees is an additional parameter needed to improve the characterization, especially of lakes with small surface area. Data collection on wind fields and dynamic water temperature profiling in lakes, impacted differently by the blowdown, will allow us to develop the deterministic relationships by which the impact of shoreline vegetation on lake temperature stratification, especially of small lakes, can be projected. Temperature stratification is a crucial limnological characteristic with a huge impact on a lake's water quality and biology.

4. Develop a relationship between wind sheltering and sediment re-suspension in BWCAW lakes impacted by blowdown.

   As wind affects water circulation and wave action in a lake, it also impacts suspended sediment re-suspension. Turbidity measurements under different weather events and in lakes of variable degrees of windsheltering can provide information on this question. Measurements would be intermittent. Weather data will also be needed for this field work.

Theme 4. Primary and Secondary Production

Most ecological study on terrestrial-aquatic linkages relevant to a large-scale forest blowdown comes from the Hubbard Brook Experimental Forest in the White Mountains of New Hampshire. In a classic set of studies, Borman and Likens (1970, 1979) examined

changes in streamflow and chemistry resulting from the cutting and leaving in place of all trees in a maple-beech forest located in a single watershed. This major disruption resulted in a great increase in the concentration of base cations (calcium, sodium, and magnesium) in the stream leaving the watershed; these ions were in effect titrated out from the soil via acid in precipitation.

However, the base-poor soils of the boreal forest in the BWCAW likely will not respond like the richer soils in the Hubbard Brook study. A study in some ways comparable to Hubbard Brook examined the aquatic chemical changes resulting from large-scale windstorm and subsequent forest fire in Ontario just north of the BWCAW in a very similar landscape (Schindler *et al.* 1980, 1996). One of the main outcomes of the Canadian study was the realization that predicting ecosystem response to such a major perturbation was very difficult. The forest fire study also occurred in the context of a decadal scale warming of climate, making the comparison particularly apt for northern Minnesota in the coming years, where global change models predict significant increases in temperature. Changes in boreal lakes as a consequence of warming and disrupted forest in the watershed were reduced chemical inputs from catchments (a consequence of lower streamflow), warmer temperatures, deeper thermoclines, clearer waters, higher alkalinities, and higher concentrations of base cations. In contrast, organic carbon, silica, and phosphorus showed reduced concentrations. These responses, too complex to fully interpret here, were brought about by landscape-level interactions between vegetation, soil, hydrology, and limnology.

Although these ecosystem components are major factors in northern Minnesota aquatic ecosystems, effects of the blowdown and subsequent anticipated fires and forest recovery on primary and secondary production cannot at this point be predicted. Microbiota in the nutrient-poor, organic-carbon-rich lakes of northern Minnesota will be responding to changes in physical, chemical, and biotic conditions. For example, Fee *et al.* (1996) observed that reduced DOC as a result of lowered hydrologic flushing time (exposing DOC to high intensity light at the lake surface for a greater time) resulted in deeper mixing patterns. Deeper mixing in turn means a greater light-dependence of primary production. However, changes in nutrient inputs, which are a product of terrestrial soil processes and ground water hydrology, will also be a factor. Secondary production (zooplankton) will likely respond both to changed algal standing stocks and to changes in fish communities brought about by the habitat disruption. Large-scale monitoring of phytoplankton chlorophyll can depend on remote data gathering from satellites or from RUSS units, but changes in plankton communities need to be assessed locally, either through sonar or optical counting methods or by direct counts. Physiological assays to assess nutrient limitation, such as alkaline phosphatase, would provide invaluable information on nutrient availability.

Changes in the hydrology due to the blowdown in northern Minnesota are likely to have important effects on aquatic ecosystems in this region. Specifically, decreased living plant biomass should decrease transpiration rates and result in increased runoff. Consequently, the mean hydraulic residence time in many of the lakes and streams should decrease relative to areas unaffected by the blowdown.

Such increased fluxes from the terrestrial to the aquatic realm should have important impacts on nutrient and organic carbon dynamics in these systems. In classic studies of the Hubbard Brook forested ecosystem, clearcutting resulted in increased export of nutrients (calcium, potassium, phosphorus, and nitrogen) from the forest (Likens *et al.* 1967). The time scale for recovery was directly related to the regrowth of tree

biomass (5-10 years). Similar patterns have been reported or modeled in other environments (e.g., Yin and Perry 1991, Dixon *et al.* 1996). We expect that a similar phenomenon will occur in the BWCAW blowdown area, but a major difference is that the blowdown area that has a much lower relief than Hubbard Brook; therefore, although we expect increased runoff, the differences should be less dramatic.

Low relief could have important impacts on nutrient and carbon fluxes in this ecosystem. Runoff should pass though considerable wetland habitat. Wetlands typically increase DOC concentrations in surrounding aquatic habitats (Gorham *et al.* 1998). Furthermore, DOC concentrations are likely to increase due to shorter residence times and less potential for UV and biological oxidation and decomposition. Although other nutrients, such as nitrogen and phosphorus, will also be mobilized through decomposition of blowdown biomass, the low carbon:nitrogen and carbon:phosphorus of decomposer biomass relative to that of trees suggests that terrestrial ecosystems are not likely to surrender large quantities of these nutrients, especially given the low physiographic relief.

DOC has important feedbacks to ecosystem dynamics through impacts on the light environment (Williamson *et al.* 1996) and primary productivity (Schindler *et al.* 1996). But these negative effects on production may be mediated somewhat by effects on the thermal regime of aquatic systems. Increased colored DOC in Canadian lakes decreased the mixed layer depth and the mean light level (Fee *et al.* 1996).

If hydrologic changes result in increased DOC fluxes into aquatic systems, there are likely to be important negative impacts on food quality and aquatic productivity. The shallower mixed layer depths, high light: nutrient ratios, and increased availability of high carbon: nutrient terrestrial organic matter should decrease food quality and inhibit production in higher trophic levels (Sterner *et al.* 1997). High DOC concentrations stimulate heterotrophic bacteria and enhance the microbial loop over other portions of the food web, thereby further decreasing trophic transfer efficiencies to the metazoan food web because of the many transfers that occur within the microbial loop (Ducklow *et al.* 1986, Cotner and Biddanda 2000). High DOC loading and microbial loop components are likely to shift many of the lakes in the BWCAW to being more heterotrophic, with decreased net production.

The proposed research will provide important information on the effects of windfall on northern boreal ecosystems. It will provide information on the recovery time of these nutrient-poor ecosystems and facilitate our understanding of the interactions of hydrology, terrestrial, and aquatic production. Nature has provided us with an experiment and we have a unique opportunity to take advantage of it.

The proposed work has important management implications as well. One of the most human-manipulated ecosystem parameters is hydrology. We drain wetlands to convert systems to agricultural fields. We alter flows of rivers and streams to minimize flooding. We clear forests to harvest wood. We hypothesize that the changes in the hydrology in the windfall region are likely to have negative impacts on food quality and result in decreased aquatic primary productivity.

There may also be some important impacts of these ecosystem changes on contaminant flux through these wetland-dominated ecosystems. Some of the most problematic contaminants in Minnesota boreal ecosystems are hydrophobic organics (PCBs, methyl-mercury, DDT, etc.), which behave similarly to bulk DOC in aquatic systems (Eadie *et al.* 1984). Increased DOC in the water column and increased cycling through

the microbial loop are both likely to increase bioconcentration and biomagnification of contaminants in the food chain. High DOC systems typically have low growth efficiency throughout the food chain, and low growth efficiencies imply high throughputs of organic matter with little ensuing biomass accumulation. Low growth efficiency could increase the potential for non-bioactive pollutant compounds to accumulate, would help explain why low productivity systems have high bioconcentration factors (Meili 1997), and would help explain why biomass in small, heterotrophic microbes, with low growth efficiencies, reaches equilibrium rapidly with hydrophobic contaminants (Broman *et al.* 1996). If increased loading of DOC increases the importance of the microbial loop and decreases growth efficiencies or aquatic organisms, it seems likely that contaminants will bioaccumulate in these food webs relatively efficiently.

High Priority Research

We propose to use both *in situ* and remote measurements to examine the influence of the blowdown on productivity and carbon fluxes. These measurements will be focused on the following questions:

1. Has the blowdown increased DOC fluxes into aquatic ecosystems?

2. Has the blowdown and its related changes decreased net productivity in aquatic ecosystems?

3. Will the blowdown shift aquatic systems from dominance by the metazoan food web to dominance by the microbial loop?

The basic construct for answering these questions will be to examine many different aquatic systems along a disturbance gradient over a long time period (20 years). We will examine watersheds of different sizes with differing degrees of disturbance. By examining the recovery of these ecosystems over a long time period, we will be able to describe and predict how ecosystem function changes along this temporal gradient. We predict that the most severely impacted systems will move along a trajectory toward their previous steady state. Our work will determine the time scale of that trajectory.

To accomplish such goals, we will make both *in situ* and remote measurements. The bulk of the *in situ* measurements will be made with a RUSS auto-profiling system deployed in 10-15 lakes. These systems will be set up to measure conductivity, temperature, depth, pH, and dissolved oxygen. Water column measurements will be made hourly throughout the ice-free season and up-loaded to a land-based station for data retrieval. Conductivity, temperature, and depth (CTD) measurements will be used to estimate mixed layer depth and changes in stratification seasonally, and diel oxygen measurements will be used to estimate productivity (Schmidt and Conrad 1993). We will estimate water-air oxygen fluxes from wind speed and diffusion fluxes from the literature.

Other *in situ* measurements will include Secchi depth and PAR profiles to estimate light attenuation in each lake and water samples for determining DOC, nutrients (dissolved and particulate carbon, nitrogen, and phosphorus) and community composition (phytoplankton, zooplankton, and bacteria). We will use a particle counter to determine the mean size of particulate matter in each lake so that we can estimate particle fluxes from the euphotic zone to the sediments.

Remote Measurements

Chlorophyll is a major parameter that fortunately can be monitored in a large set of lakes using satellite imagery. These data, obtained at

fine temporal scale, will be used to evaluate the major hypothesis of this study, namely that the windstorm changes the patterns of spatial and temporal variability in the landscape. These data will need to be ground-truthed.

Theme 5. Changes in Benthos, Fish, and other Aquatic Organisms among and within Lakes, Streams, and Wetlands

High Priority Research

1. Measure changes in benthic invertebrate communities among lakes, streams, and wetlands along a gradient of blowdown and fire impact.

   Benthic invertebrates are the base of many aquatic food chains and are highly indicative of changes in ecosystem structure and function (Perry and Vanderklein 1996). In most northern Minnesota aquatic ecosystems, most energy is cycled through the metazoan food loop. We have hypothesized that the blowdown will change the principal focus of that cycling to the microbial loop. We also suggest that there will be significant changes in nitrogen, phosphorus, sediment, and temperature (e.g., theme 3 and Brezonik *et al.* 1993, Likens *et al.* 1970, Martin and Pierce 1980). In addition to increases in runoff, temperature (T), and nutrient input, we expect reductions in external carbon litter inputs (i.e., leaves). We might also expect to see changes in litter quality with the eventual shift in vegetation (e.g., Bartodziej and Perry 1989, Murphy and Meehan 1991). We predict that those changes in temperature, nitrogen, discharge, and perhaps phosphorus will result in short-term increases in primary productivity. However, processing of both carbon and nutrients will be faster. That increase, associated with reductions in leaf litter input, will result in a shift in community structure. The short-term effect might be faster but longer spirals (i.e., the systems may be more leaky). In the long term, we see nutrient depletion and further oligotrophication of northern Minnesota systems if major nutrient export occurs from leaky aquatic ecosystems and the forests begin to retain nitrogen, phosphorus, and carbon within the new growth. If those hypotheses are proven correct, there will be significant shifts in the predominant benthic organisms (i.e., community structure) and in the ways those organisms cycle energy (i.e., community function).

   The blowdown is a unique opportunity to assess these likely changes in biogeochemical inputs and processes and their effects on the biota on a large spatial scale. We will document species assemblages within aquatic systems and express those changes relative to unimpacted conditions in northern Minnesota. We will choose a subset of the lakes and streams to sample each year. We will use a stratified randomized block experimental design where a subset of water bodies is sampled consistently through time and another subset is sampled every several years. Benthic invertebrates in lakes will be sampled with Hester Dendy plates; stream organisms will be sampled with colonization samplers as well as point-in-time devices such as Hess samplers.

2. Measure changes in fish communities in lakes and streams as a function of changes in carbon dynamics and physical properties.

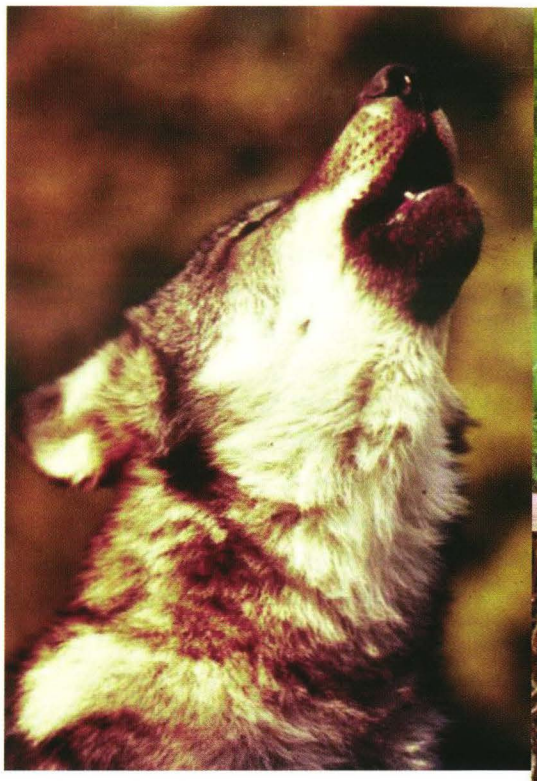
   Fish communities are predicted to shift in response to direct effects of changes in thermal habitat, flow regime and availability of structure (woody debris), but also in response to indirect effects on benthic and planktonic invertebrates, and changes in

nutrient and carbon inputs and productivity. Boreal lake and stream fish derive significant energy from allochthonous sources, which will shift after the blowdown, fires, and subsequent vegetational succession (France 1997a,b). Although Gresswell (1999) believes salmonid communities are adapted to infrequent fire and predicts few long-term impacts or extinctions of fish due to fires, he notes that few studies have examined the effects of fire on large spatial or temporal scales. The large scale of the blowdown and the likelihood of a temporal and spatial mosaic of landscape and riparian conditions provides an excellent opportunity to assess these changes on broad temporal and spatial scales. Such studies are needed to truly understand the effects of fire across a broad geographic area (Gresswell 1999).

Fish communities will change species composition as well as age and growth structure as a function of altered flows from the landscape. In lakes that warm or receive more nutrients than unimpacted conditions, fish community productivity will increase. There may be a concomitant change in species composition (e.g., an **increase** in species that feed in the water column and those that feed on small fish, and a **decrease** in those that feed on benthic organisms). We will document population shifts as well as changes in growth rates.

The Minnesota Department of Natural Resources has conducted lake surveys since 1935 (Moyle 1946). The current lake survey database contains information on 5,625 lakes. In addition to the results of monitoring fish populations with standard techniques, the database contains information on physical and chemical characteristics. Schupp (1992) used the database to develop a lake classification system based on these physical and chemical characteristics and then related the fish community composition to the classification. This long-term database could provide a historical perspective on the fish community before the blowdown and could be used in conjunction with our proposed surveys to assess whether or how fish communities change. We will use the same collection equipment and procedures to provide compatibility between data sets.

One of the significant results of this analysis will be an increased understanding of how these communities respond to major and sequential disturbance at this coarse geographic scale. This element also will provide central input to analyses of valuation and recreation and economic changes as a result of these disturbances.



Focus Group Leaders: Richard Buech, North Central Research Station; and Alan Haney, University of Wisconsin-Stevens Point.

Focus Group Contributors: Clay Edwards, North Central Research Station; Melissa Grover, Robin Vora, and Ed Lindquist, Superior National Forest; Peter Jordan, University of Minnesota; Mark Lenarz, Minnesota Department of Natural Resources; Dave Mech, U.S. Geological Survey.

In this research assessment, we focused on four themes: (1) threatened, endangered, and sensitive species (TES); (2) landscape-scale ecosystem processes; (3) stand-scale ecosystem processes; and (4) aquatic ecosystems. The research identified below is organized as a series of research objectives itemized under these broad themes that address the current blowdown state. We assume that should fire occur, research would be expanded to include that new state.

Theme 1. Threatened and Endangered Wildlife Species Responses to Large-Scale Wind and Fire Disturbance

Megafauna and especially endangered, threatened, and sensitive species usually receive top

priority in an evaluation of the impact of any sort of disturbance, anthropogenic or otherwise. The following is a prioritized list of research needs relative to TES species.

High Priority Research (in descending order)

1. Determine how wolves are responding to storm-caused changes by monitoring territories of wolves and those of their prey.

   Dr. Mech has been monitoring wolf packs and white-tailed deer living within and adjacent to the affected blowdown area for many years. Because the mobility of large mammals has likely been affected by the aftermath of the storm, this research would observe near-term changes in the distribution of both wolves and their prey (mostly moose).

2. Determine how raptors are responding to storm-caused changes by surveying and monitoring territories, nest sites, and productivity of species such as bald eagles, ospreys, northern goshawks, and boreal owls.

   These raptors were likely affected by the storm on both national forests through loss of nesting trees, and for some, possibly reduced availability of prey.

3. Determine how rare birds are responding to storm-caused changes by ensuring that methods used to survey and monitor birds include the presence and abundance of species such as boreal chickadees, black-throated blue warblers, bay breasted warblers, and Connecticut warblers.

4. Determine how rare small mammals are responding to storm-caused changes by surveying and monitoring presence and abundance of rock voles, heather voles, and northern bog lemmings.

   These species are potentially indigenous to the blowdown area and could be affected by storm-induced changes. Our understanding of their life history is very poor—probably too poor to predict how they are affected.

5. Relocate and monitor known rare plants and rare plant communities, especially the location of TES species. Expand this to conduct a survey for rare plants in blowdown areas, and especially in planned prescribed fire areas and any natural fire areas for at least 5 years.

   Other than trees, plants were poorly covered by focus groups represented at the workshop. At minimum, we need to identify plants at risk and their location in the blowdown area. In reality, many questions similar to those posed for wildlife need to be addressed for plants. In particular, we need a much better understanding of the effects of blowdown and fire on TES plants. TES species are poorly represented in the Fire Effects Information System. Thus, the focus group recommends, devoting similar resources to research on the understory as well as the overstory.

6. Determine how great blue herons are responding to change brought by the storm.

   These herons nest colonially in the tops of mature trees in lowland areas and are likely affected by the aftermath of the storm through loss of nests and nesting trees.

7. Determine how Canadian lynx are responding to storm-caused changes by surveying and monitoring the occurrence and abundance of snowshoe hares and lynx.

The lynx is currently under review by the U.S. Fish and Wildlife Service for inclusion under the Endangered Species Act as a threatened species. Lynx may be indigenous to the blowdown area, but their abundance in Minnesota is very low and cyclically tied to the abundance of snowshoe hares. They could benefit from the storm if snowshoe hares respond positively to increased availability of forage and cover.

8. Re-evaluate suitability of habitat for woodland caribou to determine whether there has been a change in potential to restore this species to Minnesota.

   Caribou were indigenous to the near-boreal forests of northern Minnesota as recently as 1940. Recent habitat evaluations have led to the conclusion that the best, if not only, suitable area in the state for restoration of caribou stretches from Little Saganaga Lake in the BWCAW northward and westward into the Quetico Wilderness. This region was heavily impacted by the storm.

Theme 2. Wildlife Responses to Landscape-Scale Disturbances in Forest Structure and Composition

The windstorm changed forest characteristics at several spatial scales. In this section, the focus is the landscape scale. The size and extent of 1999 blowdown patches on the Chippewa National Forest (NF) are more typical of what generally occurs during storms in this region, where blowdown patches up to several hundred acres are common. For example, the Government Land Office records (1840-1856) from the Luce District in the Upper Peninsula of Michigan indicate that mean size of blowdown patches was around 169 ha (Zhang *et al.* 1999). Stearns (1949) provided examples of blowdown patches of a similar magnitude, some reaching up to a few thousand hectares. In contrast, the blowdown on the Superior NF exceeded 190,000 contiguous hectares.

Blowdowns of the usual size in the Midwest typically affect only a few individuals. Seldom are blowdown patches large enough to encompass a subpopulation of a species, even for species with small territories. However, the 1999 blowdown on the Superior NF was certainly large enough to affect subpopulations of a species, even for those with large territories, such as wolves, bears, and ungulates. In fact, it has probably impacted the metapopulation dynamics of many species.

Despite the magnitude of the blowdown, variability in the susceptibility of different forest stands to wind damage, variation in topography, and variability in the wind event itself likely produced a heterogeneous outcome on the landscape. Areas of complete blowdown are interspersed with areas where few or no trees blew down. This tends to mitigate the impact of the wind disturbance because refugia are interspersed within the affected landscape. We can expect such refugia to play a role in providing a source of immigrants for repopulating disturbed areas.

High Priority Research (in descending order)

1. Classify species by how they are affected by the wind and fire disturbance: benefit (+), detriment (-), or not affected (0). Examine determinants of patterns within these categories.

   Many species are associated with specific patterns and characteristics of forest stand structure and composition. Thus, we can

expect "winners" and "losers" and a subsequent redistribution of species.

2. Identify the important storm-caused landscape-scale effects on wildlife and plants.

   We tend to have a better picture of smaller versus larger scale phenomena. This is especially true of large-scale wind disturbance in the Midwest; it simply doesn't occur that often.

3. Determine if heterogeneous patterns of blowdown are of consequence to wildlife and plant species.

   Heterogeneity tends to leave residual patches of original forest that are minimally affected, which can serve as refugia in an otherwise heavily impacted landscape. Such areas can provide a source for repopulating nearby areas and thus function in a metapopulation sense.

4. Determine long-term successional trends in biological communities as the landscape recovers from wind and fire disturbance.

   Forest composition is currently a mixed hardwood-conifer forest. Removal of the tree canopy is likely to move the landscape towards a more hardwood dominated composition. A regenerating early successional forest such as an aspen sucker stand will harbor a different community than that same forest stand at maturity. Although predictions can be made about which species are expected to recover over time, our understanding of the successional pathways triggered by wind and fire disturbance of this magnitude is rudimentary.

5. Determine whether there are any differences in how species respond to small versus large patches of disturbed habitat.

   Most disturbances produce small patches of disturbed habitat. The large scale of last year's storm provides a rare opportunity to study the effect of patch size on species composition.

6. Determine whether there are any differences in how species respond to large-scale wind versus fire disturbance.

   Windstorms produce forest stand characteristics that differ strikingly from what fires produce. The 1999 storm provides a rare opportunity to learn how large-scale wind and fire disturbance differ in their effects on biological communities.

Theme 3. Wildlife and Plant Responses to Stand-Scale Disturbances (Wind and Fire) in Structure and Composition

The most obvious effect of the windstorm is the prevalence of horizontal, leaning, and broken tree boles. The dense jungles of tree boles in parts of the blowdown area probably impede the travel of large mammals perhaps to the point of excluding their presence on part to all of their territories. This could well increase territorial conflict as individuals shift their territories. The leveling of the tree canopy also likely affects species dependent on the tree canopy, especially birds and mammals such as raptors and squirrels that forage and nest in tree crowns. On the other hand, the jumble of tree boles also provides cover for smaller species, and it should be beneficial eventually to species dependent on coarse woody debris (CWD). Broken tree boles will eventually provide den sites for mammals and hole-nesting birds. The amount of CWD will attract insects, which will benefit insectivores such as shrews and woodpeckers.

Wind-caused disturbance to the tree canopy produced a change in the amount of light penetrating to lower vegetative strata in the forest. Something similar occurs during epizootics of forest tent caterpillars. Plants in the understory exist primarily in a vegetative, non-reproductive state until foliage in the tree canopy is removed. This condition allows light to reach the forest floor; as a result, some plants dramatically increase production of foliage and flowers and other plants that are adapted to shade wither under the intense light. We can expect a similar response from wind-caused disturbance of the tree canopy, which should benefit wildlife foraging on these vegetative components of the forest.

High Priority Research (in descending order)

1. Determine how large mammals are responding to storm-induced changes by surveying and monitoring presence and movements of black bears, moose, and white-tailed deer.

   Large mammals as a group are likely to be physically excluded from large portions of the landscape by jumbles of fallen tree boles. This could reduce the use of blowdown areas by these species.

2. Determine the role and function of wildlife in recovery from disturbance.

   Some wildlife are likely to impinge on the path of forest recovery. Small mammals may affect the availability of seed for regenerating the forest community. Insect populations may build up to epizootic levels in the CWD and weakened trees, but this might be attenuated through an influx of woodpeckers. We need research to help us better understand such processes.

3. Determine how keystone species respond to large-scale blowdown disturbance.

   Beavers, for example, will respond to a potential increase in availability of water to take advantage of a more secure access to food. Food available to beavers should also increase with an increase in early successional forests. These factors could increase the number of beaver ponds on the landscape and the communities associated with them.

4. Determine response of amphibians to changes in CWD by examining and comparing both under blowdown, fire, clearcut, and control forest conditions.

   Many amphibians, especially red-backed salamanders, use downed large CWD for cover, nesting, and/or foraging. The aforementioned forest conditions provide different amounts of CWD, which would affect the abundance of amphibians dependent on CWD.

5. Determine the potential for either an influx of new exotic species or an increase in existing exotics.

   Some exotic species respond to disturbances that move forest conditions to early successional states. Although there is not a lot of potential for this to occur among wildlife species, starlings for example, may respond to a blowdown event of this magnitude. In contrast, there may be more potential for exotic plants to invade areas disturbed by the blowdown because many exotic plant species thrive on disturbance.

Theme 4. Aquatic Systems Responses to Large-Scale Wind and Fire Disturbances

The reduction of tree canopy over such a large portion of the Superior NF is predicted to increase water yield off that portion of the landscape, which could elevate water levels of ephemeral pools, ponds, lakes, and streams, thereby benefiting some aquatic organisms. It could also result in more abundant, larger, and more persistent wetlands, which would benefit many aquatic plants, invertebrates, amphibians, and beavers.

High Priority Research (in descending order)

1. Determine how hydrologic changes induced by the blowdown affect the aquatic community, including vertebrates, invertebrates, and aquatic macrophytes.

   The windstorm probably increased water yield from the landscape. A subsequent large and intense fire could further impact both water quantity and chemistry and thus the biological community.

2. Determine patterns of blowdown in riparian forest areas, especially CWD, and determine the impact of this on fish and other aquatic organisms.

   Aquatic systems are strongly driven by allochthonous input of nutrients and organic matter from adjacent riparian and terrestrial systems. It would help to understand the degree to which there is increased input of CWD, whether there are any patterns discernible in blowdown within riparian areas, and what effect this has on the aquatic community.

3. Determine how changes in riparian areas affect the aquatic community.

   Changes to aquatic systems and adjacent riparian and upland systems produced by the windstorm and a potential subsequent fire will affect a range of aquatic species. These species are dependent in part on food and nutrients originating from aquatic as well as adjacent riparian and terrestrial systems.

Theme 5. Miscellaneous Topics

Several topics arose during the feedback sessions that fell outside the themes listed above, yet are important to consider.

1. Define wildlife; what does it include, especially in regard to smaller animal forms that are usually ignored.

   The definition of wildlife has changed through time, from a focus on huntable species to a definition that is more inclusive of "all" species in current times.

2. Determine how the blowdown (and potential fire) will affect wildlife experiences of visitors, especially visibility of notable species.

   Early research in the BWCAW documented the importance of wildlife as highlights in the wilderness experience of visitors. Hearing wolves and loons; seeing moose, deer, beavers, Canada jays; and even watching chipmunks forage about campsites are often high points in visitors' days. In addition to the dramatic change in the appearance of the landscape, the blowdown could also have affected visitors' ability to see important wildlife species.

3. Determine if any wildlife or plant issues should be addressed if prescribed fire is proposed.

   Fire, whether prescribed or not, will further change habitat conditions on the landscape with an attendant change in the wildlife and plant community in both the short and long term. It would be particularly important to address TES species issues in or near any area where fire is prescribed to create a firebreak against naturally occurring fire or to reduce fuel loads.

4. Improve our understanding of the response of wildlife to habitat change by linking fire and fuel models to wildlife models and testing predictions generated by such combined models.

   The blowdown provides an opportunity for creating combined habitat models. And, because most models have not been tested, it provides a good opportunity to test the efficacy of wildlife models.

5. Explore the efficacy of Habitat Suitability Index (H.S.I.) models for selected species as a tool for predicting their response to blowdown and/or fire.

   Many models were developed for selected species, yet most have not been tested. The blowdown provides an opportunity to test the thinking that went into these models.

Cross-Cutting Research Needs

One glaring omission noted in coverage of focus groups was the lack of a group that dealt with plant species other than trees and their silviculture. One person even suggested that "wildlife" be broadened to include all wildlife; anything alive, plant or animal. Regardless, it was a serious enough omission that in our final revision, we broadened the scope of our focus group to include plants.

1. Conduct a detailed survey of existing vegetation (post blowdown, including a spatial representation of degrees of blowdown) and incorporate it into a GIS layer. This will be a valuable future reference for monitoring plant succession, effects of any potential fires, etc.

2. Coordinate surveys of vegetation and other habitat elements to ensure that information important to interpreting wildlife observations will be available.

3. Develop a list of previous and/or existing studies in or near the blowdown area, including documentation of methods, study sites, databases, results, etc.

4. So far as possible, ensure that all species are consider ed for study. Although we will have to prioritize because of inadequate resources to cover all species, we should be deliberate in considering what to include and omit.

5. Develop a standard protocol for quantitatively characterizing CWD and/or fuel, including both horizontal and vertical characteristics.

Focus Group Leader: Lee Frelich, University of Minnesota.

Focus Group Contributors: Roy Rich and Peter Reich, University of Minnesota; Sara Webb, Drew University; Chris Peterson, University of Georgia.

Theme 1. Describing the Pattern of Storm Damage

Predictive models of forest damage during disturbance cannot be developed without knowledge of the key variables that govern damage, such as tree size and condition, stand age, and stand physiographic position. In addition, predicting the responses of the forest to disturbance requires detailed knowledge of species, sizes, and spatial distributions of surviving trees. Spatial assessment of damage is also necessary to put studies of response by all components of the biotic system into strata of disturbance severity.

The following forest inventory work must proceed in parallel to permit description of forest initial conditions.

1. Resample, mark, and protect all pre-existing permanent and semi-permanent vegetation plots for long-term study. The pre-storm context is invaluable and will allow us to (for example) track changes, test models of succession, evaluate the role of new recruitment vs. advance regeneration vs. seed banks, and compare windstorm responses in different forest types. Parallel plots outside the blowdown zone must also be resampled and maintained in matching forest types to serve as controls.

2. Install new networks of permanent plots as needed to ensure long-term study across the

full range of windstorm intensities, at a variety of scales, and at a variety of forest community types (including control areas not disturbed by the storm). To assess the resilience and the future of the forest communities, we need data on patterns of tree regeneration and on other plant populations as well.

High Priority Research

1. Measure the spatial distribution and number of disturbed areas by gap size, severity of damage, forest type, stand age, and landform.

2. Measure the frequency of tree damage by species, size of tree, and landscape position.

Theme 2. Monitoring Forest Regeneration After Major Disturbance

The overarching principle of studies listed here is to gauge the long-term forest response to both managed and unmanaged disturbances in terms of forest resiliency, or the ability of the system to recover after disturbances of varying severity and/or size. This research must be linked with and compared to the silvicultural research being done outside the wilderness. In addition, the wilderness itself provides the opportunity to compare the resiliency of second growth and primary forest, since the blowdown area straddles the primary/secondary forest interface.

Little is known about near-boreal forest responses to gradients in disturbance severity and size. Theories that predict linear, discontinuous, or cusp-like responses with alternate states have been published, but it is not known with certainty which types of responses occur under which conditions. The BWCAW blowdown created a unique opportunity to examine these issues in long-term studies. How is resiliency of the forest community related to stand type, site productivity, and species diversity? In theory, unlogged stands should be more resilient than second growth, and diverse stands on moderately productive sites should be more resilient than mono-dominant stands on high or low productivity sites.

The unique structures created by the blowdown, such as coarse woody debris and tip-up mounds, will be especially important in windthrown forests, since they play a key role in regeneration in conifer forests and are closely linked to pathogens, insects, and fuels that help determine the mortality and reproductive rates of surviving trees, and the outcome of post-blowdown fires.

High Priority Research

1. Measure forest regeneration responses to various treatments (blowdown and fire in all combinations). The response to both size and severity of wind and fire would be assessed in a stratified design including stand type, landform type, and a three-part breakdown of forest status: primary forest versus secondary forest within the wilderness versus actively managed forest outside the wilderness (the latter through linkages with the silviculture group).

2. Measure patterns of microsite diversity and abundance resulting from blowdown. Are these patterns predictable based on stand characteristics, and how do they influence stand response at larger scales? These questions would be studied on highly detailed mapped plots arranged in the same stratification as theme 1: stand type, landform, stand age, and forest status (primary, secondary, actively managed). Decomposition rates of coarse woody debris, bryophyte succession, and (in due time) colonization by trees and other vascular plants will be important to follow under all the conditions

represented by the research design and stratification.

3. Measure the blowdown and subsequent fire impacts on threatened and endangered species and rare plant communities. The Natural Heritage Program database of occurrences of these biotic features would be overlaid on the storm-damage map to find sites to visit for long-term studies, methods for which may vary widely depending on the species or community.

Lower Priority Research

4. How will plant-animal interactions change as a result of the blowdown, especially ungulate herbivores (moose and deer) as well as small mammals and insects? Patterns of movement and browsing may change, which will necessitate observing herbivory on the same plots and stratifications used for themes 1 and 2, and linking these movements across the landscape.

Theme 3. Ecosystem Ecology—Storm Effects on Nutrient Cycling

The BWCAW has the only near-boreal forest complete with upland black spruce in the 48 contiguous states, making the nutrient cycling system there and its response to disturbance unique in the U.S. Some parts of the blowdown have thin soils over bedrock; in some other areas the soil is purely an organic moss layer. Thus, parts of the disturbed area are more susceptible than average to nutrient loss by runoff or burning. The future productivity of these stands is in doubt, making for an important research topic. Also, theories about nutrient cycling have not been tested after disturbance at the massive scale of the Fourth of July blowdown. Experimental studies have been limited to much smaller areas. Moreover, unforeseen consequences may occur when the scale of disturbance is very large; the response may not be a simple multiple of many small disturbances.

High Priority Research

1. What are the consequences of different levels of disturbance severity for the rates of nutrient cycling, distribution of nutrient pools among the various compartments, and future of stand productivity? Nutrient cycling work with major limiting elements such as nitrogen would be done sharing the same plots and stratification by disturbance severity, stand type, age, landform type, and forest status (primary, secondary, or actively managed) as for the forest regeneration studies.

Theme 4. Population Biology and Genetics—Storm Impacts on Genetic Structure

Disturbance can alter the genetic structure of populations by selectively killing individuals with certain characteristics (in this case larger size would make a tree more susceptible to disturbance). A second mechanism by which disturbance can change genetic structure is by changing the environment of the forest floor, thereby putting tree seedlings through a selective filter. The post-blowdown cohorts may have a different genetic structure and composition than the adults they will replace, and microsite variability and distance from seed and pollen source may also influence genetic structure. These topics have not been addressed to any great extent for the tree species of interest in northern Minnesota.

Lower Priority Research

1. How did the blowdown immediately alter the genetic structure of the dominant tree populations (jack pine, red pine, white pine, black spruce, balsam fir, white cedar, aspen, and paper birch) in terms of allele frequencies, genotypic diversity, levels of heterozygosity, and spatial genetic patterns? This research question could be answered by comparing the genetic structure of the population of trees that blew down with the genetic structure of trees that survived.

2. What are the long-term consequences of this blowdown for the genetic structure of dominant tree species, as mediated by establishment of new genotypes? Comparison of the genetic structure of the populations of new seedlings with existing adults for various forest types and different levels of disturbance severity would answer this question.

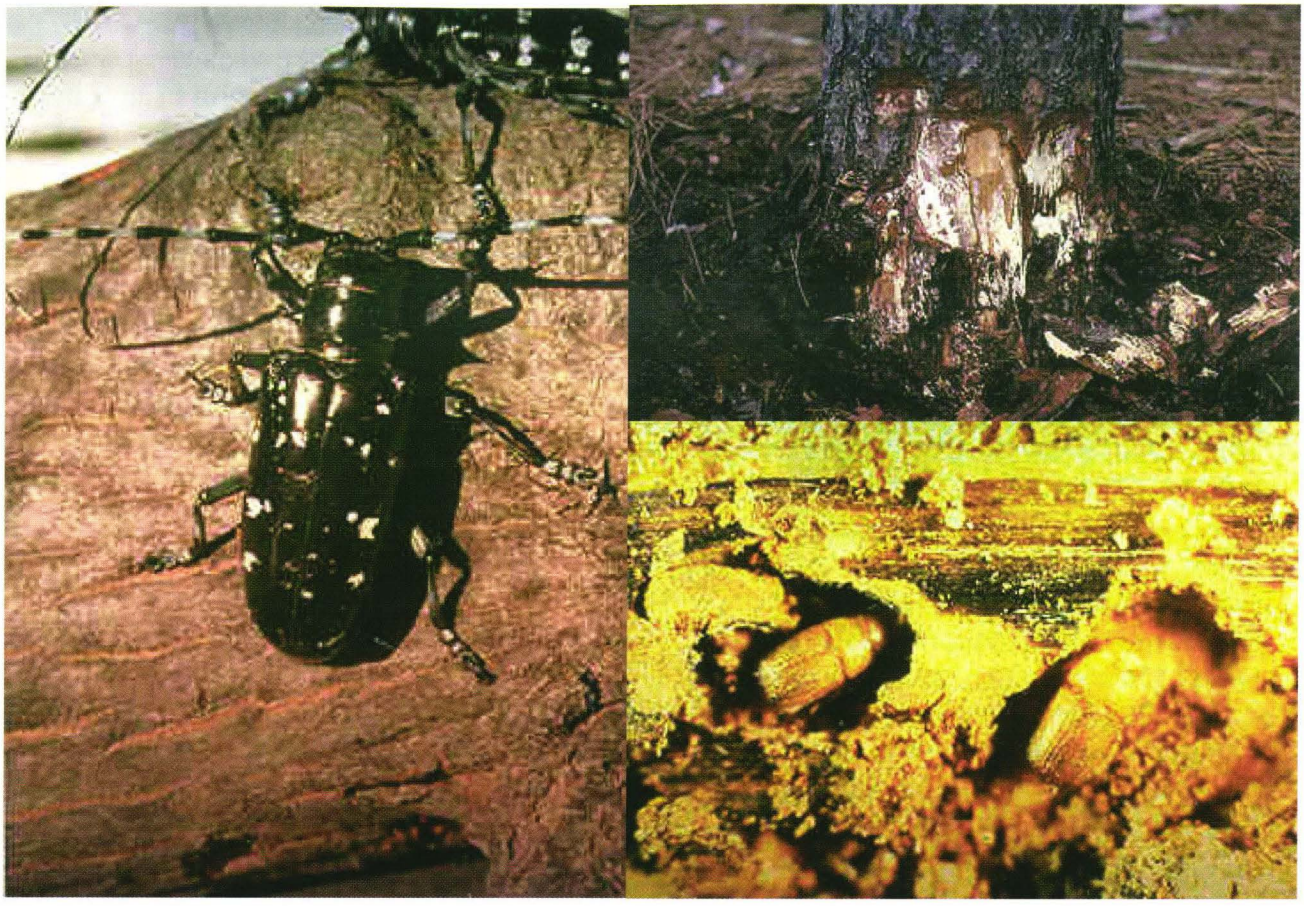
Other Issues and Conclusions

Three issues other than research themes emerged from our focus group. It will be necessary to deal with these issues in conducting a major, long-term research program in northern Minnesota.

1. We should seek a large, interdisciplinary, integrated study of biotic response to disturbance, including wildlife, insects, and terrestrial forest response. All studies would use the same stratification: (1) forest logging status (primary, secondary, or actively managed); (2) forest type before blowdown, forest age class before blowdown; (3) level of blowdown damage (and/or fire damage when that occurs); and (4) soil or landform type. These studies should start immediately (y. 2000) and be carried out over the long term, with periodic remeasurement. The studies should also take advantage of previously established plots and fill in any gaps by establishing new plots.

2. Forest managers at the Forest Service, the Minnesota DNR, county forests, and major private landowners interested in ecosystem management should be included in design and data transfer aspects of the disturbance research.

3. Some predetermined mechanism is needed to provide continuance and organizational structure to long-term research in the blowdown areas. Many previous long-term research efforts have faltered because a key person moved or retired. The most benefits of the proposed research will come 10-20 years after the blowdown.



Focus Group Leader: Bill Mattson, North Central Research Station.

Focus Group Contributors: Mike Albers, Minnesota Department of Natural Resources; Lee Frelich and Steve Seybold, University of Minnesota; Joe O'Brien and Steve Katovich, State and Private Forestry; Paula Anderson, Therese Poland, and Mike Ostry, North Central Research Station; and Bill Ciesla, Fort Collins, CO.

Theme 1. Outbreaks of Insects and Pathogens Kill Trees Surviving the Blowdown

Experience has shown that storm-damaged trees may provide abundant breeding materials for root pathogens (RP), and wood boring insects, such as bark beetles (BB) and wood borers (WB). However, the injured trees must be in the appropriate condition (e.g., med-high moisture content, low resin flows, low callus formation, etc.) to permit insect population buildups and eventually outbreaks that may spread to undamaged trees and forests. The following general questions may be addressed for each affected tree species and its phytophagous organisms. The objective is to better understand the factors determining whether BB, WB, and RP populations become "epidemic" and attack and kill healthy trees both within and outside of the blowdown area, thereby further altering the initial forest conditions after the blowdown.

High Priority Research (in descending order)

1. What classes (broken, down, leaning, standing but now open grown, etc.) and sizes (small to large diameter) of storm-injured trees are most suitable for colonization by BBs and WBs? Likewise, which are most susceptible to root pathogen buildups? After colonization, what is the reproductive potential of BBs and WBs in different classes and sizes of storm-injured trees? In other words, which trees and which tree components (upper, middle, and lower bole; large branches, small branches?) provide the most fuel for BB and WB population increase?

2. What environmental circumstances (soils, stand condition, disturbance area, weather conditions (temperature and moisture), root pathogens, defoliations, distance from storm-generated brood materials, etc.) may permit WBs and BBs to attack and kill putatively healthy, standing trees within and beyond the margins of the storm-damaged area?

3. What is the fate of different species and classes of storm-injured trees? Develop a "life table" for trees in different conditions/circumstances, and then follow their survival curves; the insects, pathogens, and invertebrates causing their death; and rates of decay.

4. Only aggressive species of bark beetles and wood borers are capable of attacking healthy and nominally weakened trees. Therefore, monitoring beetle alightment, colonization attempts, and reproductive success on putatively healthy, nominally stressed trees, highly stressed and downed trees will reveal differences in success rates by different species of beetles: aggressive species on mildly stressed trees, and nonaggressive species on highly stressed trees

5. Does salvage harvesting, prescribed fire (at different scales), etc., substantially reduce the risk of local BB and WB population buildups, and thus reduce the risk of insect-caused mortality in undamaged to moderately damaged forests?

6. Will bark beetles and wood borers provide an unprecedented abundance of food for various species of birds, especially woodpeckers, thereby attracting birds even from outside of the blowdown area, and thus be subject to population regulation by bird predators?

Theme 2. Insect and Pathogen Impacts on the Trajectory of Forest Succession

Under the various disturbance conditions created by the blowdown, it is highly likely that insects and pathogens will affect the course of natural reproduction and regeneration, and thus the trajectory of plant and community succession. For example, the surviving overstory conifers will be subject to the concentrated attacks of seed and cone insects for several years. Moreover, these seed trees will also be prone to attacks by bark beetles, wood borers, and root pathogens that may in fact kill the crucial sources of seed. Only jack pine has a seed bank that was created before the storm and may be available for eventual regeneration, circumstances permitting. The objective is to better understand the role of insects and pathogens in the establishment and growth of tree seedlings and saplings, and their influence on trajectories of forest succession following massive disturbances.

High Priority Research (in descending order)

1. Will seed and cone insects and pathogens limit the natural seed production of the surviving conifers in the blowdown areas and thus prevent their reproduction from establishing?

2. What is the impact of insects and pathogens on the growth and survival of seedlings and saplings; will they significantly affect the direction of plant succession?

3. Can we construct novel hazard zones for predicting white pine regeneration success based on pathogen and insect limitations and land type phases?

4. On those sites where artificial regeneration will be used, should we select against those tree species highly prone to insect outbreaks and subsequent tree mortality? For example, should there be selection against balsam and white spruce because of their propensity for promoting spruce budworm populations to outbreak and initiate tree decline and mortality?

Theme 3. Invasion, Expansion Opportunities for Exotic Organisms

Wedging themselves into natural, nearly pristine ecosystems is not the usual means by which invasive organisms enter new environments. But, removing vast areas of native plant and animal communities creates nearly ideal opportunities for exotic species to suddenly increase their geographic ranges and general abundance. This entry of new species into an ecological matrix can substantially alter usual pathways of succession and ecosystem biodiversity. The objective is to better understand (a) how disturbances increase the opportunity for the invasion, establishment, and increase in abundance of exotic species, and (b) how exotics subsequently impact their adopted plants and ecosystems.

High Priority Research (in descending order)

1. Will exotic soil dwelling, root feeding weevils (*Polydrusus* spp., *Sciaphilus asperatus*, and *Phyllobius oblongus*) and the two dozen or so species of introduced earthworms substantially increase in abundance in the disturbed environments; displace native species; and impact forest productivity, plant-plant competition, natural succession, and carbon sequestration through heightened loss of fine tree roots?

2. Will *Ribes* shrubs, the alternate host for the exotic pathogen, white pine blister rust, proliferate in response to forest opening and hence increase the frequency and severity of white pine blister rust infections on the primary host, white pine?

3. Will exotic herbivores such as the introduced pine sawfly (*Diprion similis*) on white pine and the introduced mountain ash sawfly (*Pristiphora geniculata*) on mountain ashes substantially increase in abundance and impact their adopted host plants to affect growth, reproduction, succession, and ecosystem function? Will several species of exotic sawflies (*Allantus* spp., *Caliroa cerasi*) that feed on shrubs such as wild roses, raspberries, currants, June berries, and hawthorns substantially increase in abundance and impact their adopted hosts to affect growth, reproduction, succession, and ecosystem function?

Theme 4. Riparian and Aquatic Systems: Insects and Pathogens

Aquatic insects live in ephemeral forest pools, ponds, streams, rivers, and lakes, all of which will be impacted by the blowdown mainly because of less evapotranspiration by trees and, therefore, altered levels of water, but also because of altered inputs of coarse woody debris and litter. Following snowmelt and rains, ephemeral pools and ponds of water will be larger on average and last longer in heavily and moderately damaged forests because of less evapotranspiration and evaporation. The objective is to better understand how disturbance changes the abundance of aquatic organisms.

High Priority Research (in descending order)

1. Will insects (esp. the key links in the aquatic food chain) of streams and rivers that were heavily impacted by the blowdown have altered levels of abundance because of an extraordinary input of coarse wood debris and substantially altered long-term inputs of litter and sunlight?

2. Will insects of ephemeral forest pools, such as *Aedes* mosquitoes and others (e.g., caddis flies, dytiscid beetles, etc.), be more abundant in areas of heavy and moderate forest destruction because of longer breeding and growing periods?

Theme 5. Understory, Litter, and Belowground Processes (Invertebrates, Mycorrhizae)

The objective is to better understand how windfall disturbances alter the poorly understood lesser vegetation communities (shrub and herb layers) and the soil-litter community. Emphasis is given to the soil-litter system because it is so fundamental to the life of the entire forest and because its condition translates into altered growth and susceptibility/defense of plants to pathogens and herbivores, nutrient uptake, and nutrient cycling.

High Priority Research (in descending order)

1. Do storm-induced influxes of litter and coarse woody debris substantially alter populations and communities of soil-litter processing organisms, thereby altering rates of organic matter turnover and nutrient cycling?

2. Do prescribed burning, salvage harvesting, and soil compaction (various intensities) substantially alter the populations and communities of soil-litter processing organisms? If so, for how long?

3. Do massive influxes of woody debris and/or prescribed burning so alter soil organic matter and the complex soil-litter milieu (composition and abundances of bacteria, fungi, protozoans, invertebrates, and their activity) and nutrient availability that plant growth and defensive allocations are altered, thereby changing plant susceptibility to root pathogens, and belowground and aboveground herbivory?

Theme 6. Biodiversity Responses to Disturbance

The biodiversity responses to single and multiple disturbance of various severity and extent are very poorly understood basic processes. Such knowledge is fundamental to better holistically manage forests and landscapes. Little

substantive knowledge is available about the total complexity of the insect and fungal life within different systems and subsystems of the near-boreal forests.

High Priority Research

1. How has the insect and fungal biodiversity of the forest changed as a consequence of massive windfalls and the subsequent management treatments (burning, harvesting, etc.)?

Focus Group Leaders: Daniel Williams, Rocky Mountain Research Station; and David Lime, University of Minnesota.

Focus Group Contributors: David Bengston and Deborah Carr, North Central Research Station; Don Bruns, Bureau of Land Management; David Cole and Alan Watson, Aldo Leopold Wilderness Research Institute; Bill Gartner, Jayne Fingerman Johnson, and Leo McAvoy, University of Minnesota; Steve McCool, University of Montana; Joe Roggenbuck, Virginia Polytechnic Institute; George Peterson, Rocky Mountain Research Station.

This social science research assessment identified a range of possible research questions organized under three research themes. The themes are described in order of priority. These priorities are influenced by two factors: (a) the degree to which information can affect immediate policy and mitigation efforts and (b) knowledge of the first themes tends to inform research on the later themes. Within themes, however, more work would be necessary to generate specific priorities. This is partly due to the shortness of the workshop and to the interrelatedness of studies within each theme.

Theme 1. How Are Recreation and Tourist Visitors to Northern Minnesota Affected by the Storm Damage, its Aftermath, and the Recovery Effort?

Northern Minnesota is an internationally recognized natural resource-based tourist region. In addition to its many vacation homes, the region is famous for its water-based wilderness canoeing and fishing. The damage associated with the Fourth of July storm was centered on some of the most attractive and heavily visited tourist and recreation areas of the region, particularly the Boundary Waters Canoe Area Wilderness. Consequently, a very high research priority is to understand how recreationists and tourists are affected by the storm. First, many social and environmental impacts and management and policy responses hinge on a good understanding of tourist/recreationist behavior changes. Second, impacts on tourists and visitors are secondarily manifest as impacts on local community residents, businesses, and community infrastructure. Responses to the storm damage and its aftermath and recovery efforts may take a variety of forms. These include various types of behavior change (visitation levels, displacement across sites, and site-specific behaviors related to compliance with rules and regulations, etc.). The storm damage, its aftermath, and recovery efforts will likely not affect all users equally. Some individuals and groups may experience little or no negative impact while others will experience substantial impacts; it is even possible some will receive positive impacts due to the storm and related recovery efforts.

The study of visitors and tourists also affords a number of areas where biophysical studies can be integrated with social science questions. Two major areas are (1) perceptions of and preferences for vegetation management prescriptions and (2) the influence of environmental features in recreation and tourist choice models.

High Priority Research

1. A study of the short- and long-term behavioral responses to the storm damage, its aftermath, and the recovery efforts.

    a. What are the short- and long-term changes to visitation patterns and use distribution within the BWCAW and other tourist destinations and how, if at all, should the current distribution model for the BWCAW be modified to account for changing use patterns to protect the

resource and manage the carrying capacity of the BWCAW?

b. Does any displacement of recreational and tourists use occur as a result of the storm damage? How are visits redistributed both internally and externally to the damaged region? How does that displacement vary by social and demographic group and what are the equity implications of any changes regarding access to any part of the national forest?

c. Do BWCAW users modify behavioral practices in the BWCAW (e.g., length of stay, style of camping, fire practices, recreational activities) as a direct result of the storm damage?

d. How do environmental features associated with the storm damage influence recreational and tourist decisionmaking?

2. A study of visitor/tourist knowledge about the storm and damage, natural disturbances, and their environmental consequences and visitor/tourist preferences for management and policy actions for recovery and mitigation.

a. What has been the use and effectiveness of existing environmental education programs, and what additional programs might be developed to facilitate awareness of issues, management concerns, and behavioral adjustments on the part of forest users in response to the storm and its environmental impacts?

b. How aware are tourists/visitors of agency responses to the event, and how do they evaluate actions taken so far and additional actions being contemplated by the Forest Service?

c. How do tourists'/visitors' perceptions and behaviors condition evaluations of agency mitigation efforts and preferences for possible future policy/management decisions?

d. How do tourists and recreationists perceive the fire risk relative to other risks in the outdoors, and how do these perceptions influence management preferences and use of and behavior within recreation sites?

e. What are tourists'/visitors' expectations about responsibility for and acceptance of environmental hazards and risks?

f. What is the level of compliance with rules and regulations for forest visits among tourists/visitors?

3. A study of visitor/tourist perceptions of the storm damage, landscape, and agency responses.

a. What are the aesthetic perceptions of the storm-damaged vegetation (and resulting insect-damaged vegetation), and how do these vary by type of site (including lake, riparian, campsite, portage, etc.), type of damage, and in comparison to undisturbed sites?

b. How are tourist/visitor images of northern Minnesota and the BWCAW affected by the storm and related media coverage?

c. How are tourist/visitor perceptions, understandings, and meanings associated with the concepts of "wilderness," "natural," and "natural disturbance" affected by the storm, and how do these

perceptions influence policy/management preferences for the BWCAW and other wildland settings?

d. What has been the role and influence of media representations of the storm on tourist/visitor perceptions of the BWCAW and surrounding landscapes as well as public perceptions of the management responses and possible additional management actions?

e. How do perceptions of the storm vary across social groups including race, gender, disability, income, occupation, and level of commitment and interest in the BWCAW?

f. How do tourists/visitors perceive and evaluate the emergency responses of the Forest Service and other land management agencies?

4. A study of the impact of the storm damage, its aftermath, and recovery efforts on visitor experiences.

   a. What are the emotional and experiential impacts on a BWCAW visit of the storm damage, its aftermath, and recovery efforts, and how does this vary between casual and highly attached/committed visitors to the BWCAW?

   b. Do motivations for visiting the BWCAW and other northern Minnesota tourist destinations change as a result of the storm damage?

   c. Do the storm damage and recovery efforts affect the wildlife-related recreational experiences of visitors to tourist sites in northern Minnesota?

   d. What impact, if any, has the storm and resultant change to the BWCAW and northern Minnesota tourist destinations had on the distributional equity regarding access and ability to use and enjoy these recreation sites?

Theme 2. What are Local Residents' and Non-resident Property Owners' Expectations, Concerns, and Responses to the Storm Damage, its Aftermath, and Recovery Efforts? What Are Economic and Business Consequences?

This theme is the second highest priority and in important ways builds on understanding how visitors and tourists are impacted (theme 1). First, local residents are also visitors and tourists either because they use the same recreational resources as non-residents or because many residents in the region are seasonal or part-year residents, but they must live with the consequences of the storm and its aftermath on a daily basis. Consequently many of the questions about behaviors, perceptions, and preferences of tourists and visitors are equally relevant to community residents. Second, the lifestyles, jobs, and income of many residents are derived from the tourist industries, so an important component of the research under this theme includes economic impacts. In addition, understanding residents' views and behaviors is important to the eventual success of any recovery and mitigation efforts. Finally, local residents are often indirectly impacted by changes to social institutions, community resources, etc.

High Priority Research

1. A study of residents' and part-year residents' attitudes, perceptions, and behaviors in response to the event, its aftermath, and the recovery effort.

    a. What actions do residents and property owners take to mitigate fire and other safety hazards?

    b. How are local residents' patterns of forest use and recreation impacted by the storm, its aftermath, and the recovery effort?

    c. How do perceptions of the community change among community residents?

    d. How do community residents perceive and evaluate agency responses to the storm damage, and how do they perceive roles and responsibility for mitigation?

2. A study of economic impacts on local businesses and the regional economy affected by the storm and storm recovery efforts.

    a. What is the overall damage cost assessment of the storm?

    b. What are the tourism economic and regional economic impacts of the storm and the resulting policy/management actions?

    c. How are the economic impacts distributed both within subregions of the affected economy and by sector?

    d. What are the impacts of the storm damage, its aftermath, and the recovery effort on non-market values of environmental amenities?

    e. What are the impacts of the storm damage, its aftermath, and the recovery effort on property values?

3. A study of impacts on community institutions.

    a. What role has the affected landscape and the BWCAW in particular played in local community life and identity, and how are these aspects of community impacted by the immediate storm, post-storm environmental consequences (e.g., risk of fire), and resulting mitigation efforts and policy changes?

    b. What are the positive and/or negative impacts of the storm damage, its aftermath, and recovery efforts on community resilience and social capital?

    c. What institutional changes and impacts (distribution of political power, changes in community structure, creation of new organizations and businesses) result from the storm, its aftermath, and the recovery effort?

Theme 3. What are the Stakeholder, Resource Agency, and Institutional Impacts and Responses to the Storm Damage, its Aftermath, and the Recovery Effort?

Although the primary impacts of the storm damage tend to be felt most directly by tourists and residents, other important actors in environmental and natural resource policies need to be considered to fully understand the impacts of sudden large-scale environmental change on social systems. Here it is important to recognize that recovery efforts and future management of the forest will affect various stakeholders,

management agencies, and other significant institutions. First, many stakeholders are not just the passive recipients of impacts, but they also attempt to influence management and policy, so it is important to understand how these types of organizations attempt to influence the mitigation and recovery effort.

Second, social science research can make critical contributions to guiding management responses to this storm and future large-scale environmental changes, as well as advancing the scientific understanding of environmentally induced social change. From the standpoint of natural resource policy, any large-scale natural event creates unique opportunities to advance natural and social science. However, the fact that this large-scale "natural" disturbance has occurred in a unique and highly valued wilderness area adds even more to the potential scientific and policy benefits of a strong social science research program examining public perceptions and reactions to this event. There is a well-developed social science research tradition of examining human responses to natural hazards, but existing research work has been associated almost exclusively with impacts to human settlements as opposed to "natural areas." The wilderness context of this event, in terms of both the resource itself and the management practices allowed to occur within its boundaries, provides a special laboratory in which to examine and begin to quantify values attributed to wilderness. Most importantly, tracking the human consequences, responses, and adaptations that come from large-scale environmental change has important research value in preparing society for major environmental change associated with global climate changes. Understanding how a region is impacted and how it responds as a social system to catastrophic environmental change may provide theoretical, substantive, and methodological insights that can be used to organize and prepare social institutions to more effectively respond to environmental changes likely to occur in the future.

High Priority Research

1. Studies of local and non-local stakeholder groups.

    a. How do the actions and policies of various BWCAW and other resource-oriented interest groups change as a result of the storm?

    b. Do groups modify or take new positions on environmental policies such as salvage logging, wilderness management, fire management, etc.? Do groups deal with other, adversarial groups in new or different ways?

    How can various stakeholder groups be mobilized via public involvement activities to assist in the creation of a desired future condition for the storm-impacted area?

2. A study of environmental managers' and resource agencies' perceptions, values, and actions. What is the public acceptance and perceived effectiveness of agency actions in response to the storm and recovery efforts?

    a. What are the long-term impacts of this event on Forest Service policies and capacities to respond to catastrophic events, both in terms of mitigation/management efforts and research? What can be learned from the Forest Service response to this event that might be applied to responses to future large-scale environmental changes?

3. A study to evaluate the impacts of sudden large-scale environmental change research

on methods and institutions of science and other institutions.

a. What are the social knowledge and methodological contributions of studying human responses to natural disasters?

b. What critical baseline studies of human/social adaptation to large-scale environmental events are the most useful for advancing scientific understanding of such events and for guiding policy decisions that flow from such events?

c. How are national environmental organizations, non-governmental organizations, and government institutions impacted by this event?

Comments on the Logic Underpinning Recreation, Tourism, and Social Science Research Needs Assessment

The preceding discussions and recommendations are structured around three organizing issues.

The focus group also identified two additional dimensions to its analysis of themes. These dimensions related to the geographic and social scale of analysis and the types of affected groups.

Dimension 1. Identification of Varying Social, Geographic, and Temporal Scales of Impacts

The geographic/social and temporal scales were seen as useful and important ways to structure analysis. Different research themes focus on one or more geographic scales or units. Categorizing geographic units is somewhat arbitrary, but these units potentially include:

a. The area of vegetation affected by the storm itself.

b. The Boundary Waters Canoe Area Wilderness.

c. The Superior and Chippewa National Forests.

d. The directly affected geographic region (e.g., northern Minnesota).

e. Larger geographic regions and scale (e.g., national wilderness system, etc.).

f. International scale (e.g., as a border region with Canada).

Similarly, there is a closely related issue of social scale. By social scale, the human dimensions focus group noted that impacts and responses can be observed at:

a. Individual level.

b. Social (e.g., families) and demographic groups (e.g., race, income).

c. Organizations (e.g., Forest Service, business associations).

d. Communities (e.g., Grand Marais, Ely).

e. National (e.g., American Society).

f. International entities and institutions (e.g., United Nations).

Finally, with regard to time scale, it is important to recognize that responses and adaptations unfold over short and long periods of time.

Dimension 2. Identification of Potential Affected Groups and Stakeholders

The range of actors and institutions that may be relevant and/or the focus of each research theme includes, but is not limited to:

a. Northern Minnesota tourists/visitors (both local and non-local in origin).

b. Northern Minnesota outfitters and guides.

c. Other tourist operators and businesses in northern Minnesota.

d. Specific social and demographic groups (e.g., income, race, ethnicity, disability, gender).

e. Community residents and non-resident property owners (immediately proximate to the storm, northern Minnesota, state, etc.).

f. Organized interests, stakeholders, and institutional actors (e.g., environmental, business groups).

g. Government institutions and actors.

h. Land management agencies with specific jurisdiction.

i. The general public.

j. Scientists.

k. Media organizations.

The purpose of the workshop was to identify critical, immediate, and high priority research questions that would be instrumental in guiding policy and management decisions. However, beyond guiding immediate policy decisions, to understand how social systems respond and adapt in the long run to such events, it is important to recognize that any list of research priorities is bound to miss the whole by characterizing the pieces. Thus, the research topics and issues listed above represent aspects of what should be a comprehensive case study of social adaptation to environmental change, and they need to be considered in terms of their collective value and not just their individual priority. Some aspects are likely to have immediate payoff in terms of informing policy decisions and management actions. Others will have important payoffs in evaluating the long-term effectiveness of agency and institutional responses to the storm.

There have been a number of analogous events such as the eruption of Mount Saint Helens, Hurricane Hugo, and the New England ice storms, and the focus group asked what has been learned from these in terms of the social and economic consequences. Managers and policymakers need immediate advice on any number of pending decisions. The focus group recognized and set as a high priority an effort to identify existing research; the group noted that to learn from these other events it would be helpful to undertake research (1) to examine how resources, people, and institutions were affected by these events and (2) to evaluate the effectiveness of the recovery efforts.

REFERENCES

Ahlgren, C.E. 1981. **Seventeen-year changes in climatic elements following prescribed burning**. Forest Science. 27: 33-39.

Ahlgren, I.F.; Ahlgren, C.F. 1965. **Effects of prescribed burning on soil microorganisms in a Minnesota jack pine forest**. Ecology. 46: 304-310.

Bartholow, J.M. 1989. **Stream temperature investigations: field and analytic methods**. Instream Flow Paper 13. U.S. Fish and Wildlife Service Biological Report. 89(17). 139 p.

Bartodziej, W.; Perry, J.A. 1989. **Litter processing in diffuse and conduit springs**. Hydrobiologia. 206: 87-97.

Bates, C.G.; Henry, A.J. 1928. **Forest and streamflow experiment at Wagon Wheel Gap, Colorado**. Monthly Weather Review Supplement. 30.

Bolgrien, D.W.; Kratz, T.K. 2000. **Lake riparian areas**. In: Verry, E.S.; Hornbeck, J.W.; Dolloff, C.A., eds. Riparian management in forests of the Continental eastern United States. Boca Raton, FL: Lewis Publishers: 207-218.

Bormann, F.H.; Likens, G.E. 1970. **The nutrient cycles of an ecosystem**. Scientific American. 223: 92-101.

Bormann, F.H.; Likens, G.E. 1979. **Catastrophic disturbance and the steady state in northern hardwood forests**. American Scienctist. 67: 660-669.

Brezonik, P.L.; Eaton, J.G.; Frost, T.M.; Garrison, P.J.; Kratz, T.K.; Mach, C.E.; McCormick, J.H.; Perry, J.A.; Rose, W.A.; Sampson, C.J.; Shelley, B.C.L.; Swenson, W.A.; Webster, K.E. 1993. **Experimental acidification of Little Rock Lake Wisconsin: chemical and biological changes over the pH range 6.1 to 4.7**. Canadian Journal of Fisheries and Aquatic Sciences. 50: 1101-1121.

Broman, D.; Näf, C.; Axelman, J.; Bandh, C.; Pettersen, H.; Johnstone, R.; Wallberg, P. 1996. **Signficance of bacteria in marine waters for the distribution of hydrophobic organic contaminants**. Environmental Science Technology. 30: 1238-1241.

Carlson, D.W.; Groot, A. 1997. **Microclimate of clear-cut, forest interior, and small openings in trembling aspen forest**. Agriculture and Forest Meteorology. 87: 313-329.

Chen, J.; Franklin, J.F.; Spies, T.A. 1993. **Contrasting microclimates among clearcut, edge, and interior of old-growth Douglas-fir forest**. Agriculture and Forest Meteorology. 63: 219-237.

Cotner, J.B.; Biddanda, B.A. 2000. **Small players, large role: microbial influence on auto-heterotrophic coupling and biogeochemical processes in aquatic ecosystems**. Ecosystems. In Press.

Desmond, E.D.; Ward, A.D.; Fausey, N.R.; Workman, S.R. 1996. **Comparison of daily water table depth prediction by four simulation models**. Transactions of the American Society of Agricultural Engineers 39: 111-118.

Dixon, R.K.; Perry, J.A.; Hiol Hiol, F. 1996. **Carbon sequestration and conservation in forest systems: preliminary assessments in Ghana and Cameroon**. The Environmental Professional. 18: 112-118.

Dolloff, C.A.; Webster, J.R. 2000. **Particulate organic contributions from forests to streams: debris isn't so bad**. In: Verry, E.S.; Hornbeck, J.W.; Dolloff, C.A., eds. Riparian management in forests of the Continental eastern United States. Boca Raton, FL: Lewis Publishers: 125-138.

Ducklow, H.W.; Purdie, D.A.;Williams, P.J.LeB; Davies, J.M. 1986. **Bacterioplankton: a sink for carbon in a coastal marine plankton community**. Science. 232: 865-867.

Duvall, M.D.; Grigal, D.F. 1999. **Effects of timber harvesting on coarse woody debris in red pine forest across the Great Lakes States, USA**. Canadian Journal of Forest Research. 29: 1926-1934.

Eadie, B.J.; Chambers, R.L.; Gardner, W.S.; Bell, G.L. 1984. **Sediment trap studies in Lake Michigan: resuspension and chemical fluxes in the southern basin**. Journal of Great Lakes Research. 10: 307-321.

Fee, E.J.; Hecky, R.E.; Kasian, S.E.M.; Cruikshank, D.R. 1996. **Effects of lake size, water clarity, and climatic variability on mixing depths in Canadian Shield lakes**. Limnology and Oceanography. 41: 912-920.

France, R.L. 1997a. **Potential for soil erosion from decreased litterfall due to riparian clearcutting: implications for boreal forestry and warm- and cool-water fisheries**. Journal of Soil and Water Conservation. 52: 452-455.

France, R.L. 1997b. **Stable carbon and nitrogen isotopic evidence for ecotonal coupling between boreal forests and fishes**. Ecology of Freshwater Fish. 6: 78-83.

France, R.L. 1998. **Colonization of leaf litter by littoral macroinvertebrates with reference to successional changes in boreal tree composition expected after riparian clear-cutting**. American Midland Naturalist. 140: 314-324.

France, R.L.; Peters, R.H. 1995. **Predictive model of the effects on lake metabolism of decreased airborne litterfall through riparian deforestation**. Conservation Biology. 9: 1578-1586.

France, R.; Culbert, H.; Peters, R.H. 1996. **Decreased carbon and nutrient input to boreal lakes from particulate organic matter following riparian clear-cutting**. Environmental Management. 20: 579-583.

France, R.; Peters, R.; McCabe, L. 1998. **Spatial relationships among boreal riparian trees, litterfall and soil erosion potential with reference to buffer strip management and coldwater fisheries**. Annales Botanici Fennici. 35: 1-9.

Frelich, L.E.; Lorimer, C.G. 1991. **Natural disturbance regimes in hemlock-hardwood forests of the upper Great Lakes region**. Ecological Monographs. 61: 145-164.

Gash, J.H.C. 1979. **An analytical model of rainfall interception by forests**. Quarterly Journal of the Royal Meteorological Society. 105: 43-55.

Gorham E.; Boyce, F.M. 1989. **Influence of lake surface area and depth upon thermal stratification and the depth of the summer thermocline**. Journal of Great Lakes Research. 15(2): 233-245.

Gorham, E.; Underwood, J.K.; Janssens, J.A.; Freedman, B.; Maass, W.; Waller, D.H.; Odgen, J.G. 1998. **The chemistry of streams in southwestern and central Nova Scotia, with particular reference to the catchment vegetation and the infuence of dissolved organic carbon primarily from wetlands**. Wetlands. 18: 115-132.

Gregory, S.V.; Swanson, F.J.; Mckee, W.A.; Cummins, K.W. 1991. **An ecosystem perspective of riparian zones**. Bioscience. 41: 540-551.

Gresswell, R.E. 1999. **Fire and aquatic ecosystems in forested biomes of North America**. Transactions of the American Fisheries Society. 128(2): 193-221.

Gurnell, A.M.; Gregory, K.J.; Petts, G.E. 1995. **The role of coarse woody debris in forest aquatic habitats: implications for management**. Aquatic Conservation: Marine and Freshwater Ecosystems. 5: 143-166.

Harmon, M.E.; Franklin, J.F.; Lienkaemper, G.W.; Cromack, K.; Cummins, K.W. 1986. **Ecology of coarse woody debris in temperate ecosystems**. Advances in Ecological Research. 15: 133-302.

Kanciruk, P.; Eilers, J.M.; McCord, R.A.; Brakke, D.H.; Linthurst, S. 1986. **Characteristics of lakes in the Eastern United States**. Vol. 3, Data compendium of site characteristics and chemical variables. EPA/4-86/007c. Washington, DC: U.S. Environmental Protection Agency. 439 p.

Likens, G.E.; Bormann, F.H.; Johnson, N.M.; Pierce, R.S. 1967. **The calcium, potassium, and sodium budgets for a small forested ecosystem**. Ecology. 48: 772-785.

Likens, G.E.; Bormann, F.H.; Johnson, N.M.; Fisher, D.W.; Pierce, R.S. 1970. **Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook watershed-ecosystem**. Ecological Monograph. 40: 23-47.

Manguerra, H.B.; Engel, B.A. 1998. **Hydrologic parameterization of watersheds for runoff prediction using SWAT**. Journal of the American Water Resources Association. 34: 1149-1162.

Martin, C.W.; Pierce, R.S. 1980. **Clearcutting patterns affect nitrate and calcium in streams of New Hampshire**. Journal of Forestry. 78: 268-272.

Meili, M. 1997. **Mercury in lakes and rivers**. In: Siegel, A.; Siegel, H., eds. Metal ions in biological systems: mercury and its effects on environment and biology. Marcel Dekker. 34: 21-51.

Meleason, M.A.; Gregory, S.V.; Bolte, J. 2000. **Simulation of large wood dynamics in small streams of the Pacific Northwest**. Bulletin NABS. 17(1): 141. (abstract)

Mladenoff, D.J.; He, H.S. 1999. **Design and behavior of LANDIS, an object-oriented model of forest landscape disturbance and succession**. In: Mladenoff, D.J.; Baker, W.L., eds. Spatial modeling of forest landscape change: approaches and applications. Cambridge, UK: Cambridge University Press.

Moyle, J.B. 1946. **Some indices of lake productivity**. Transactions of the American Fisheries Society. 76: 322-334.

Murphy, M.L.; Meehan, W.R. 1991. **Stream ecosystems**. In: Meehan, W.R., ed. Influences of forest and rangeland management on salmonid fishes and their habitats. Spec. Publ. 19. Bethesda, MD: American Fisheries Society: 17-46.

Osborne, L.L.; Kovacic, D.A. 1993. **Riparian vegetated buffer strips in water-quality restoration and stream management**. Freshwater Biology. 29: 243-258.

Perry, J.A.; Vanderklein, E. 1996. **Water quality: management of a natural resource**. Cambridge, MA: Blackwell Scientific. 636 p.

Rosgen, D. 1996. **Applied river morphology**. Pagosa Springs, CO: Wildland Hydrology Press. 376 p.

Schindler, D.W.; Newbury, R.W.; *et al.* 1980. **Effects of a windstorm and forest fire on chemical losses from forested watersheds and on the quality of receiving streams**. Canadian Journal of Fisheries and Aquatic Science. 37: 328-334.

Schindler, D.W.; Bayley, S.E.; Parker, B.R.; Beaty, K.G.; Cruikshank, D.R.; Fee, E.J.; Schindler, E.U.; Stainton, M.P. 1996. **The effects of climatic warming on the properties of boreal lakes and streams at the Experimental Lakes Area, northwestern Ontario**. Limnology and Oceanography. 41: 1004-1017.

Schmidt, U.; Conrad, R. 1993. **Hydrogen, carbon monoxide, and methane dynamics in Lake Constance**. Limnology and Oceanography. 38: 1214-1226.

Schupp, D.H. 1992. **An ecological classification system of Minnesota lakes with associated fish communities**. Minnesota Department of Natural Resources Investigational Report 417.

Sinokrot, B.; Stefan, H.G. 1993. **Stream temperature dynamics: measurements and modeling**. Water Resources Research. 20(7): 2299-2312.

Srinivasan, R.; Arnold, J.G. 1994. **Integration of a basin-scale water quality model with GIS**. Water Resources Bulletin. 30: 453-462.

Stearns, Forest W. 1949. **Ninety years change in a northern hardwood forest in Wisconsin**. Ecology. 30: 350-358.

Sterner, R.W.; Elser, J.J.; Fee, E.J.; Guildford, S.J.; Chrzanowski, T.H. 1997. **The light: nutrient ratio in lakes: the balance of energy and materials affects ecosystem structure and process**. American Naturalist. 150: 663-684.

Theurer, F.D.; Voos, K.A.; Miller, W.J. 1984. **Instream water temperature model**. Instream Flow Information Paper 16. U.S. Fish and Wildlife Service FWS/OBS-84/15.

Verry, E.S. 2000. **Water flow in soils and streams: sustaining hydrologic function** In: Verry, E.S.; Hornbeck, J.W.; Dolloff, C.A., eds. Riparian management in forests of the Continental eastern United States. Boca Raton, FL: Lewis Publishers: 99-124.

Williamson, C.E.; Stemberger, R.S.; Morris, D.P.; Frost, T.M.; Paulsen, S.G. 1996. **Ultraviolet radiation in North American lakes: attenuation estimates from DOC measurements and implications for plankton communities**. Limnology and Oceanography. 41(5): 1024-1034.

Wolter, P.T.; Mladenoff, D.J.; Host, G.E.; Crow, T.R. 1995. **Improved forest classification in the northern lake states using multi-temporal Landsat imagery**. Photogrammetric Engineering and Remote Sensing. 61: 1129-1143.

Yin, X.; Perry, J.A. 1991. **Factors affecting nitrogen concentration of fine roots in forest communities: regression analysis of literature data**. Forest Science. 37: 374-382.

Zhang, Quanfa; Pregitzer, Kurt S.; Reed, David D. 1999. **Catastrophic disturbance in the presettlement forests of the Upper Peninsula of Michigan**. Canadian Journal of Forest Research. 29: 106-114.

Printed on recyclable paper.

Mattson, W.J.; Shriner, D.S., eds.
2001. **Northern Minnesota Independence Day storm: a research needs assessment**. Gen. Tech. Rep. NC-216. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 65 p.

Nearly 500,000 acres of forest and water were severely impacted by a powerful wind and rain storm in northeastern Minnesota on the fourth of July 1999. Trees were uprooted and snapped off in a swath that was 4-12 miles wide and 30 miles long. This document addresses the many ecological and social research needs in nine discipline areas that were generated as a consequence of this unprecedented storm event. It is intended to be a resource for research planning, for prioritizing storm-recovery management activities, and for research-related access to affected wilderness areas.

Our job at the North Central Research Station is discovering and creating new knowledge and technology in the field of natural resources and conveying this information to the people who can use it. As a new generation of forests emerges in our region, managers are confronted with two unique challenges: (1) Dealing with the great diversity in composition, quality, and ownership of the forests, and (2) Reconciling the conflicting demands of the people who use them. Helping the forest manager meet these challenges while protecting the environment is what research at North Central is all about.